DETERMINATION OF DYNAMIC PROPERTIES OF LAMINATED RUBBER-METAL SPRING CIRCULAR PLATE

MUHAMMAD HAFIZUDDIN BIN ZAHAR

This report is submitted
in fulfillment of the requirement for the degree of
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Supervisor: DR. MOHD AZLI BIN SALIM

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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DECLARATION

I declare that this project report entitled "Determination Of Dynamic Properties Of Laminated Rubber-Metal Spring Circular Plate" is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design & Innovation).

Signature	:.	....
Name of Supervisor	:	....
Date	:	....

DEDICATION

To my beloved mother and father.

ABSTRACT

The laminated rubber metal spring (LR-MS) is an equipment used on the mass structure such as building, railway, and huge machining. LR-MS act as an isolator of the structure and help to reduce vibration receive from external force, for preventing form damage on the structure. LR-MS consist of interlayer of rubber layer and stainless-steel layer which is repeatable arranged to form a LR-MS isolator. The stainless-steel layer is a metal plate used to provide strengthens for the LR-MS to withstand heavy structure. This study is done to determine the damping ratio of stainless-steel circular plate which is interlayer with rubber in the LR-MS. The damping ratio of the circular plate will be determined by using two methods are Logarithmic Decrement method and Half-Power Bandwidth method, and the data compute from the DeweTrans software of the experiment will be acquired from the dynamic properties experiment on the circular plate. The analyzed result will be compare to determine the percentage of error occur in this experiment. The result of damping ratio of the experiment on the cantilever beam shows the difference on both theoretical value and experimental value with the 21.13% percent of percentage of error. The experiment consist error during the experiment work was carried out, the error in this experiment are random error, and systematic error that cause the data taken was inaccurate and the experiment categories as unsuccessful test. The propagation of maximum amplitude in 10 cycles in each experiment done, all the peak amplitude is damped constantly varies with time. For maintaining the precision of the result, the experiment has been repeated three times and the average result among the total experiment was taken and recorded in the table. Both methods successfully proving the reliable data and result for determining the damping ratio for stainless-steel circular plate during this study.

ABSTRAK

Spring logam berlamina Getah (LR-MS) adalah satu alat yang digunakan pada struktur seperti bangunan, kereta api dan mesin besar. LR-MS bertindak sebagai penyerap getaran pada struktur dan membantu mengurangkan getaran diterima dari daya luar, bagi mengurangkan kerosakan pada struktur akibat daripada getaran. LR-MS terdiri daripada beberapa lapisan getah dan lapisan keluli tahan karat yang diulangi dan disusun untuk membentuk sebuah penyerap getaran iaitu LR-MS. Lapisan keluli tahan karat adalah satu plat logam yang digunakan untuk menguatkan lagi lapisan getah dalam LR-MS bagi menahan struktur yang berat. Kajian ini dijalankan untuk menentukan nisbah redaman plat bulatan keluli tahan karat yang dilapisan dengan getah dalam LR-MS. Nisbah redaman plat bulatan akan ditentukan dengan menggunakan dua kaedah, iaitu kaedah Logaritmic Decrement dan kaedah Half-Power Bandwidth, dengan mendapatkan data dari perisian Dewetrans. Hasil ujikaji akan diperolehi daripada penentuan sifat dinamik pada plat bulatan. Hasil yang dianalisis akan bandingkan untuk menentukan peratusan ralat berlaku dalam ujikaji ini. Eksperimen ke atas redaman menunjukkan perbezaan pada kedua-dua nilai teori dan nilai eksperimen dengan 21.13% daripada peratusan ralat. eksperimen terdiri ralat semasa kerja eksperimen telah dijalankan, kesilapan dalam eksperimen ini adalah ralat rawak dan ralat sistematik yang menyebabkan data yang diambil adalah tidak tepat dan kategori eksperimen sebagai ujian tidak berjaya. Penyebaran amplitud maksimum dalam 10 kitaran dalam setiap eksperimen dilakukan, semua amplitud pada puncak sentiasa berubah dengan masa. Untuk mengekalkan ketepatan keputusan, percubaan telah diulangi tiga kali dan hasil purata antara jumlah percubaan itu diambil dan direkodkan kedalam jadual. Kedua-dua kaedah berjaya membuktikan data yang boleh dipercayai dan menyebabkan untuk menentukan nisbah redaman untuk keluli tahan karat plat bulat semasa kajian ini.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my supervisor Dr. Mohd Azli Bin Salim for giving me this opportunity to do final year project with him. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

Secondly, I would like to thank a friends named Amirul Mustafa and Najaa Mastura for spending his time to guide me. They would share his knowledge in the field of vibration with me and guide me to do experiment. Also, I would like to thank laboratory assistant, En. Hairul for his kindness in suggesting me the suitable time to use laboratory equipment for his action saved me a lot of time.

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LR-MS	Laminated Rubber – Metal Spring
FEM	Finite Element Method
FEA	Finite Element Analysis
DAQ	Data Acquisition
ICP	Integrate Circuit Piezoelectric
BNC	Bayonet Neill – Concelman
FFT	Fast Fourier Transform

LIST OF SYMBOL

T	=	Time period
A	=	Amplitude
f	=	Frequency
δ	=	Logarithmic decrement
ζ	=	Damping ratio
N	=	Number of cycle
Q	=	Q factor
π	=	Pi
t_n	=	Peak time
F	=	Force
M	=	Mass
ω_d	=	Damped natural frequency
ω_n	=	Natural frequency
ω_α	=	Undamped natural frequency

CHAPTER 1

INTRODUCTION

1.1 Introduction Of Study

The invention of laminated rubber – metal spring (LR-MS) have helped to hold on of supporting a variety of structures such as building, bridges, huge machining, tanks or including high-precision tools, analytical equipment, instate of stability mount for base structure in order to reduce the acceleration incurred from earthquake, traffic or mechanical vibration.

Conventionally, a LR-MS used for decreasing acceleration transmitted directly to affected structures, one way of functioning as a vibration – proof supporter. This LR-MS was conventional, consist a structure composed of alternately soft rubber – like elastic plates and laminated rigid plates made of steel having negligible effect of compressive permanent strain. In order to decrease acceleration incurred from earthquake and protect the upper structure from destructive force generated by earthquake the laminated rubber structure is inclined between upper and lower structures to support the upper structure.

The situation of damping performance and stability against vertical which is, extremely important factors in any used for protection preventing destructive force generated by phenomenal vibration (A. Putra et al., 2013).

Figure 1.1: Laminated Rubber – Metal Spring (LR-MS).

1.2 Problem Statement

This project has been carried out to analyses the dynamics properties of circular plate, widely used in laminated rubber-metal spring (LR-MS) as the interlayer between metal plate and rubber layer. Furthermore, to investigate how the circular plate effect on the transmissibility performance on LR-MS, also the conversion of mechanical energy of vibrating structure into thermal energy, called as damping which is the lost to the structure's environment.

1.3 Objective

The objectives of this project are as follows:

i. To determine the dynamic properties of circular plates by using accelerometers to measure vibration response of a fixed-free circular plates.
ii. To measure the transient vibration that will illustrate the concepts of damping ratio in solid circular plates.

1.4 Scope of Study

The scopes of this project are:

i. To conduct the experiment: Measurement of damping properties to investigate the circular plates.
ii. To calculate logarithmic decrement method and half-power bandwidth method to evaluate the damping ratio and Q factor, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter comprises of the research study of this experiment. It includes the history of earlier dynamic properties experiment conducted, application of seismic isolation system, previous research, and detail information on base isolation of laminated rubber metal spring due to structural vessel because of vibration and seismic motion. Relevant sources from online articles and websites are compiled and cited to complete this literature review.

A literature review includes the current knowledge of a particular topic, contributed by theoretical and methodological findings. Searching, managing, synthesizing and writing the assessment of the literature are the few processes involved in doing a literature review. The purpose of literature review is to define and establish the area of study or research topic.

2.2 Fact and finding

From the past researcher, they have considered various situation of seismic isolation to reduce horizontal and vertical seismic load for bridges, building, railway and etc., and its effects on structure their occupants, for several detailed studies have been undertaken. Studies of the vibration transmission between the source and the structure will be considering noise and vibration in the structure. Based on the literature review, its gives the overview of the previous research in this field, with some emphasis on the task direct relevance to base-isolated structures. Various factor that influence the behavior of vibration occur, example is an earthquake on building, heavy moving vehicle on the railway, this will be dealing with problem and methods of reducing its effects.

2.2.1 Seismic isolation system

Nowadays, the further researcher from Korea Atomic Energy Research Institute by (Y. Choun et al., 2014), they found that the response of seismic isolation system effect on the variability of the mechanical properties of lead rubber bearings, the response depends on the movement for different ground motions. The researcher state that the variation in the mechanical properties of base isolator will result significant influence on the shear resistance and the acceleration response of the structure.

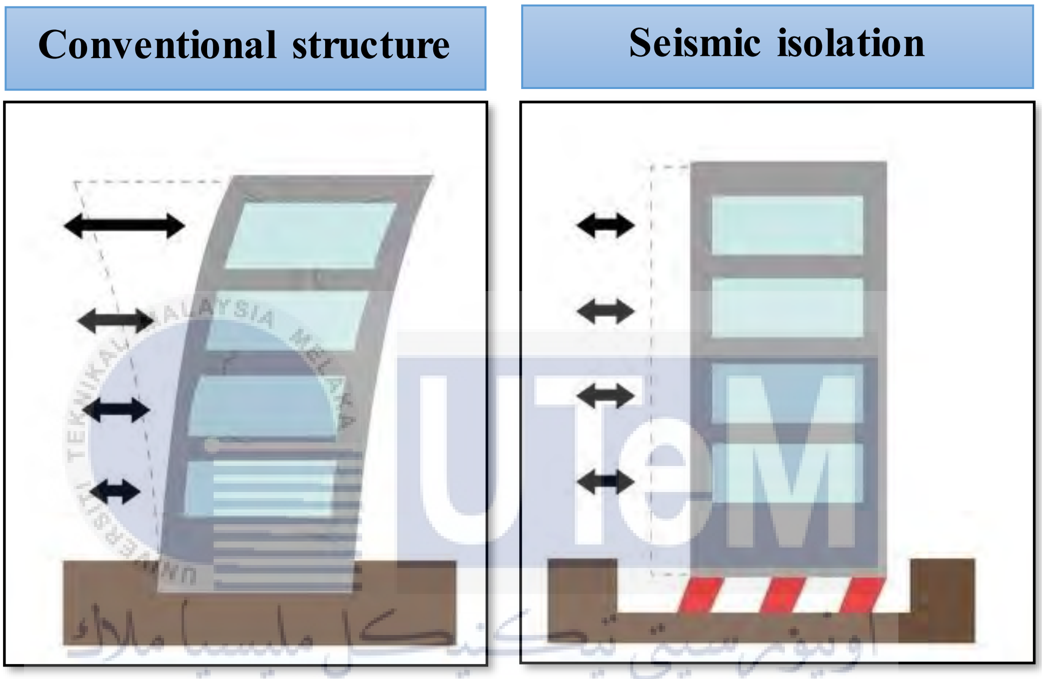

Figure 2.1: Conventional structure and Seismic isolation structure from the source (http://www.did.org.tr/eng/?page_id=47)

In the application of seismic isolation system, the building structures need to be related with safety, the different type in the materials and mechanical properties of the isolation system must be carefully controlled, furthermore to minimize the accidental torsion caused by the different similarity stiffness of variation isolators.

The factor of aging, environmental effects, and temperature in mechanical properties will contributes the stiffness and characteristic of isolation rubber metal, those the stiffness and damping values of the metal plate used for construction should be varies from other values used for design. Practically, the stiffness distribution, of based isolated system and the mass distribution of structures at the ground level can be unbalance. A low natural frequency response of structure, such as seismically isolated structures is highly sensitive to the frequency input ground motion.

2.2.2 Laminated rubber – metal spring (LR-MS)

From a previous researcher in Universiti Teknikal Malaysia Melaka, laminated rubber-metal spring is the multiple layer of rubber layer and metal plate were arranged alternating, the number of layer are determined based on the frequency vibration condition.(Chiu & Shong, 2006) By using dynamic analysis of finite element method (FEM), the performance of vibration transmissibility of LR-MS can be determined.

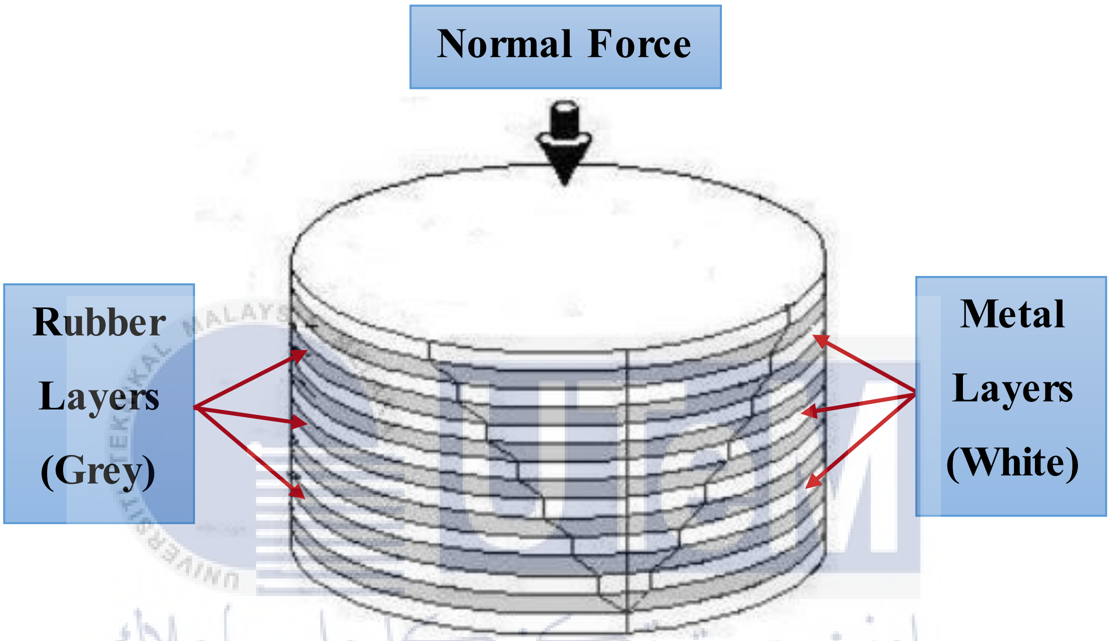

Figure 2.2: Layer of cylindrical solid rubber isolators. from the source (http://randolphresearch.com)

Previously, Statement from Salim et al (2016) the finite element analysis (FEA) method has good accuracy for analyzing cylindrical solid rubber and LR-MS isolators" and "More interlayer metal plate inside LR-MS has better transmissibility performance at higher frequency.

There are many applications used a LR-MS as their vibration absorption on superstructure to avoid for collapsing and disaster because of resonance frequency its self onto the superstructure. (Antaratana, 2015) One of the example is Penang second bridge is designed to transfer the resonant frequency of the structure away from ground earthquake vibration frequency.

Figure 2.3: Penang second bridge.

Figure 2.4: Application of LR-MS on Penang second bridge.

The behavior of LR-MS is very famous due to the capability in handling a large amount of force exerted and absorbing a vibration frequency by a natural resonance of an earthquake.(James & Kelly, 2011) Penang second bridge, Malaysia is an achievement of using LR-MS as a isolator system to the bridge and LR-MS were focused at preventing the stemming effects from the natural environment problem, such as ground motion by an earthquake (M. A. Salim et al., 2016).

2.2.3 Dynamic properties experiment

The dynamic properties experiment is a testing usually conducted to determine the vibration response of a fixed solid metal to measure the transient vibration that illustrate the concepts of damping ratio in solids (Mevada & Patel, 2016). The experiment used an accelerometer to measure the vibration response on the solid metals to capture the vibration movement occur. The same experiment method used by the previous researcher on topic determination of dynamic properties of railway tracks, shows the apparatus used to determine the frequency-dependent dynamic properties by using infinitely long embedded method on rail and supporting structures (J. Kim et al., 2014).

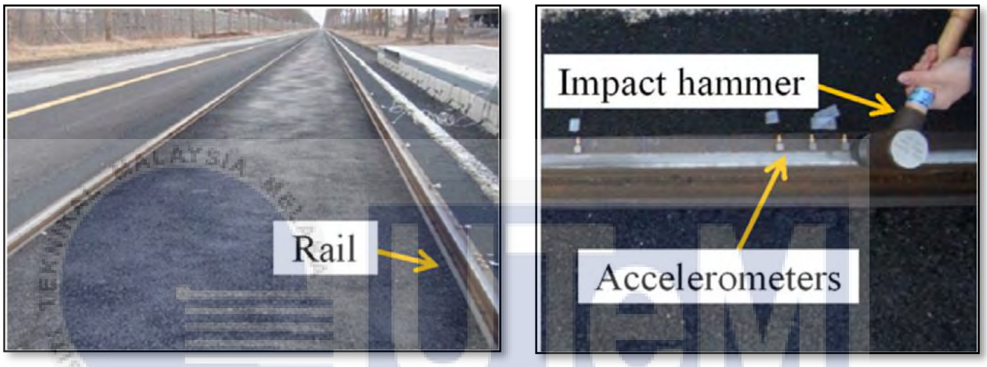

Figure 2.5: Infinitely long embedded rail and apparatus setup

The rail track were directly supported by the base pad and joined by clamping equipment, the pinned – pinned resonance frequency vibration response occur during measurement and the wavelength is equal to the half of the railway, account at high frequencies (J. Park et al., 2014).

2.2.4 Logarithmic decrement method

In estimation, the damping ratio from time based the logarithmic decrement were used, to find the propagation and uncertainties in various quantities can impact damping ratio estimates. The analysis will take the number of periods in one cycle between the first and final amplitudes then the range of multiple data use for measurement uncertainties and damping ratios.(Theses & Holman, 1969) The data will be show graphically which provides the ideal number for calculation. The calculation was applied to experiment result calculated from image processing to provide the estimation of damping ratio.

$$x(t)$$

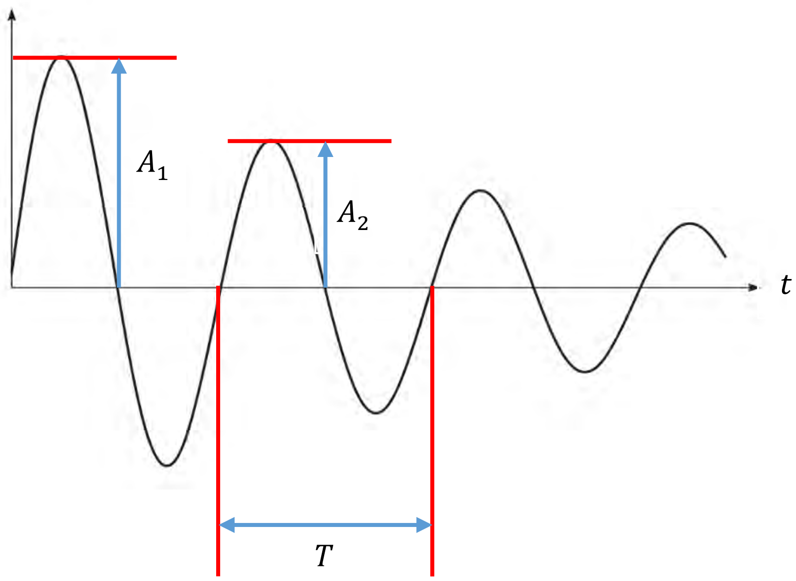

Figure 2.6: The measurement taken in logarithmic decrement.

To determine the main relationship between the selective data of final amplitudes periods from the first amplitude, measurement error, and damping occur, an analysis is apply on the logarithmic decrement method for uncertainties in the period and measurement of the displacement and general conclusion will generate in the form of a figure for a system (D. Tweten et al., 2014).

The natural frequency, ω_n and the damping ratio, ζ in damped vibration system can be represent as free vibration response. The system can be modeled by an expression:

$$x(t) = Ae^{-\omega_n t}\cos(\omega_d t - \theta) \tag{1}$$

where A is the amplitude at a peak position and θ is a phase angle of the system. The Figure above shows the plot of damped oscillation, the damped natural frequency, ω_d can be found from the oscillation period:

$$\omega_d = 2\pi f_d = \frac{2\pi}{T} \tag{2}$$

where T is the damped oscillation period of one cycle. The damped natural frequency is also can derive by

$$\omega_d = \omega_\alpha \sqrt{1-\xi^2} \tag{3}$$

where ω_α is undamped natural frequency.

The response at the peak times, t_k of each oscillation cycle, next thee amplitude of those points decays exponentially. Since the cosine function will be maximum points, therefore,

$$x(t_n) = Ae^{-\omega_n t_n} \tag{4}$$

Thus, the vibration decays with a first order system and the time between successive oscillation cycle is given by,

$$t_{n+1} - t_n = \frac{2\pi}{\omega} \tag{5}$$

Therefore, the factional amount of amplitude reduction that we see after one cycle of motion has elapsed and N is a cycle,

$$\frac{x(t_{n+N})}{x(t_n)} = \exp\left(-\frac{2\pi\xi N}{\sqrt{1-\xi^2}}\right) \tag{6}$$

The log decrement is derived as

$$\delta = \frac{1}{N}\ln\left(\frac{x(t_n)}{x(t_{n+1})}\right) \tag{7}$$

Then the damping ratio for the system can be shown as

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} \tag{8}$$

2.2.5 Half – Power bandwidth Method

The half – power bandwidth method is a method for estimating the damping ratios in single or multi degree of freedom system with linear viscous damping. This is done by deriving the calculation in the experiment that involving the single or multi degree of freedom system. In term of acceleration frequency response, the half – power bandwidth was performed, and transfer function of the structure and damping ratio estimation for the system for higher modes should be carefully calculated (G. Papagiannopoulos & G. Hatzigeorgiou., 2011).

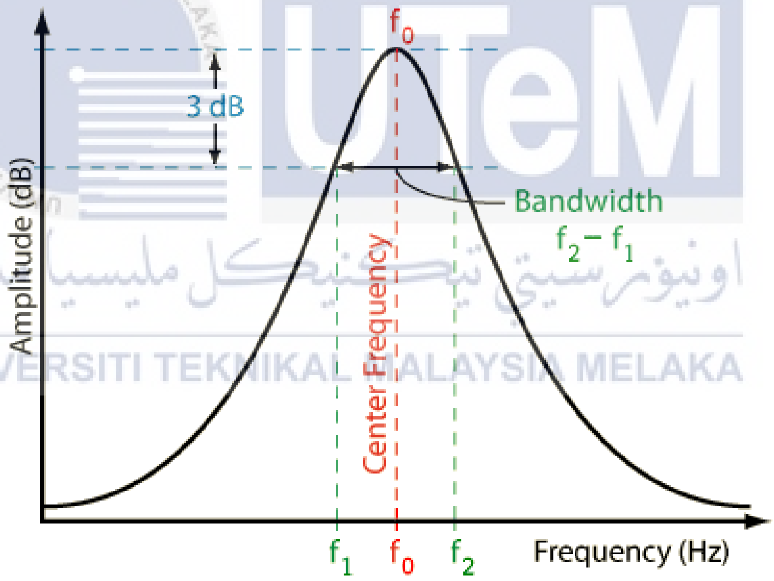

Figure 2.7: Calculating Q Factor from Frequency Spectrum. from the source (http://www.sengpielaudio.com/calculator-cutoffFrequencies.htm)

The half – power bandwidth method can be measure by using the quantitative of damping defined as,

$$\xi = \frac{1}{2Q} \tag{9}$$

Where Q is a Q factor of the frequency spectrum system.

$$Q = \frac{f_0}{f_2 - f_1} \tag{10}$$

Therefore,

$f_2 - f_1$: Bandwidth

f_0 : resonance frequency (Hz)

f_1 : upper 3dB frequency (Hz)

f_2 : lower 3dB frequency (Hz)

2.2.6 Damping in structure

Damping is a phenomenon which is mechanical energy is dissipated in dynamic systems, the mechanical energy usually converted to thermal energy. Energy from a vibrating structure used to be transform into the other form of energy is depend on the system and the physical mechanism that cause the dissipation. Most of the physical mechanism are complex process that difficulty to understand (H. Mevada & D. Patel., 2016). Therefore, any mathematical calculation of physical mechanism in the equation of motion of a system need to be an approximate and generalize of the actual physical situation.

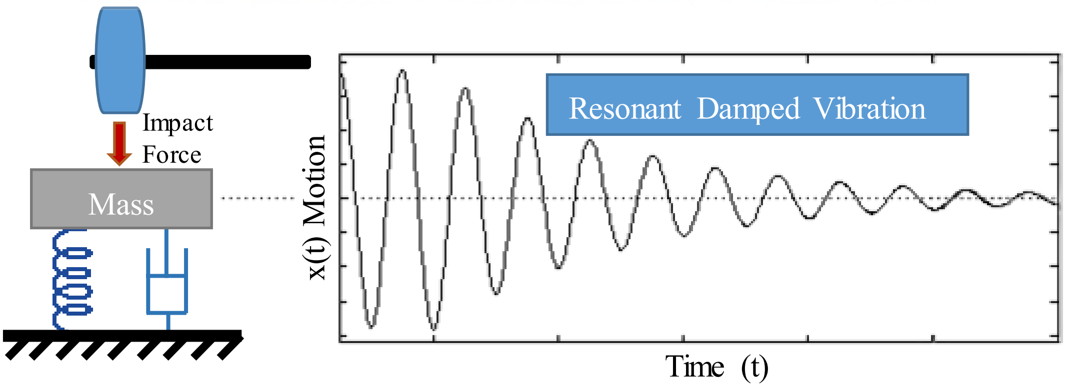

Figure 2.8: Diagram of damping propagation after an impact apply.

Based on determination of dynamic properties, the topic directly focusing on the internal damping category of damping mechanism, which is mainly involved the material characteristics (Najim & Hall, 2012). Internal Damping (of material) originates from energy from dissipation associated with:

- Microstructure defects such as impurities and grain boundaries.
- Thermo elastic effects because by the local temperature gradients.
- Eddy current effect by ferromagnetic materials.
- Dislocation motion in metals.

These are the common factor are contributes to an internal damping mechanism, which is the most difficult process in vibration analysis for damping estimation and the mechanism system it is so small to compute.

2.2.7 Stainless steel characteristic

Stainless steel is metal that has ability to withstand stains and metal rusting, more of stainless steel comes with mixture of chromium which is different properties compare to other metal. Stainless steel has low carbon steel and comes with benefits to heal itself, even having a mechanical or chemical damage.

Commercial company used stainless steel for their construction because of low maintenance, anti-corrosion, and good finish surface materials that is preferred in common construction field. Different grade of stainless steel with different their ability to add strength without increasing much on the weight.

Figure 2.9: Stainless steel circular plate.

The used of stainless steel materials as a layer in LR-MS can improve the durability on the superstructure isolation system. The combination layers of stainless steel circular plate with the rubber in isolator system will increase the stability and can improve the life withstand for a long period of time of the isolator system, also the maintenance cost decrease due to durability of the materials of the LR-MS.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is a strategies flow of the analysis, by a principle of experiment, rules, and postulates by a discipline. The process of methodology used to collect data information, the data were derived to interpret problem within the project scope, and methodology.

Its act as the procedure that may include surveys, interviews, publication research and techniques research. Most representative of the methodology used follow chart as to explain about the stages of project.

The methodology of this study is summarized in the flow chart as shown in Figure 3.1.

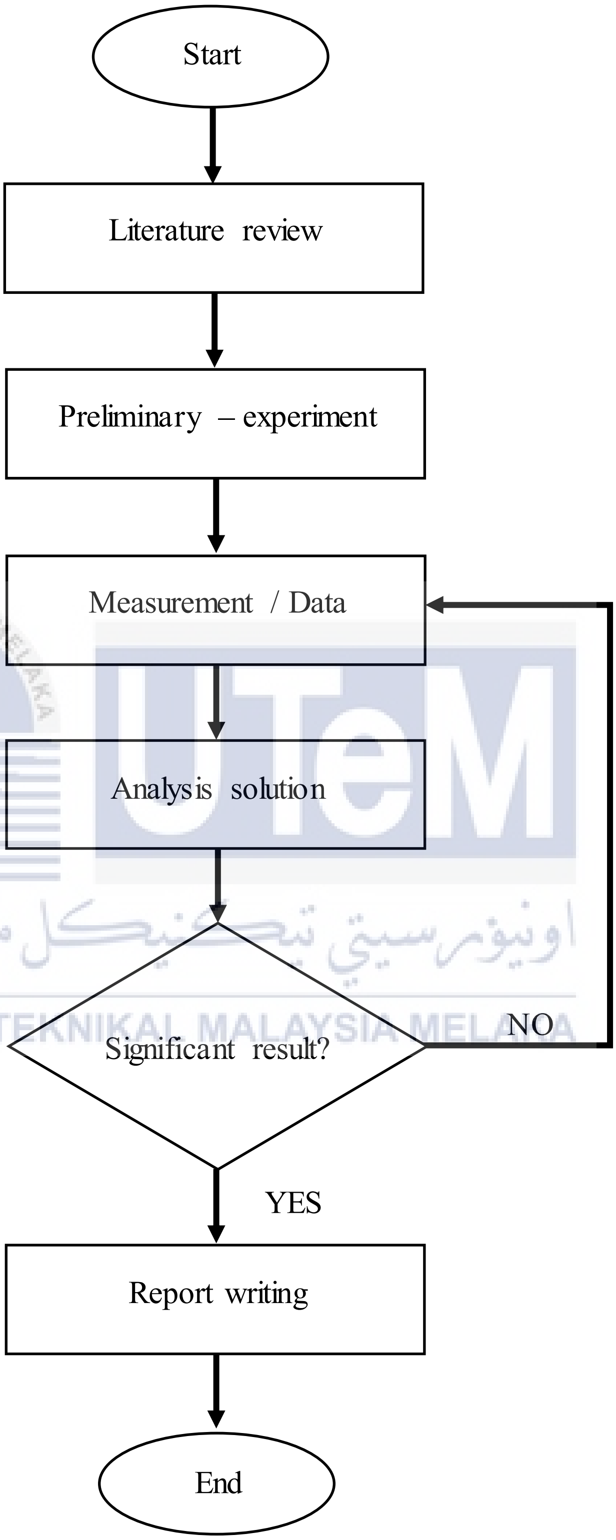

Figure 3.1:Flow chart of the study.

3.2 Sample preparation

Before conducting the experiment, a process of collecting and understanding the study from a published information about the method of experiment be used to determine the dynamic properties of the stainless steel circular plates.

3.3 Measurement and Apparatus

The measurement will be conducted at the Instrumentation and Measurement laboratory, the dimension, data from the simulation program of the structure must be taken for the further analysis and calculation. All the dimensional parameter of the testing product will be taken correctly to avoid systematic error during the experiment take place. The apparatus or experiment equipment also need to be working in good condition and no broken apparatus that will effect the accuracy of measurement.

3.3.1 Accelerometer device

An accelerometer is an electromechanical device used to measure acceleration motion or dynamic acceleration caused by moving or vibrating the accelerometer attached of the structure.(Martins, & Pontes, 2014) The motion applied will produce force causes the mass to "press gently" the piezoelectric materials which produces an electric pulse which is proportional to the force exerted and mass is constant. The electrical pulse will send the data as the output value to the systems.

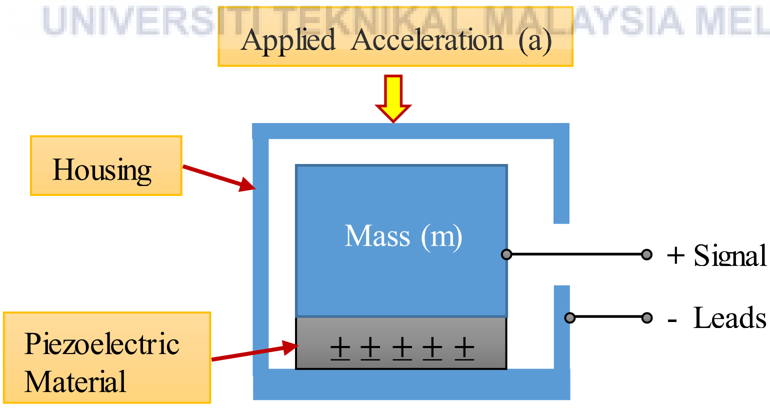

Figure 33.2: Basic Accelerometer devices.

Accelerometer is used in this experiment to measure the vibration motion on the cantilever beam and circular plate to determine the motion behavior of the materials. The device is capable to capture the displacement (amplitude) over the time taken, therefore the frequency of the materials can be determined. The higher sensitive of the accelerometer help to measure more accurate data that can improve the analysis result of this experiment.

Figure 3.3: Used accelerometer device.

3.3.2 ICP type signal conditioning

ICP is signal type of piezoelectric sensors that already built -in with microelectronic amplifiers also powered by signal conditioning, low – impedance and two wire system.

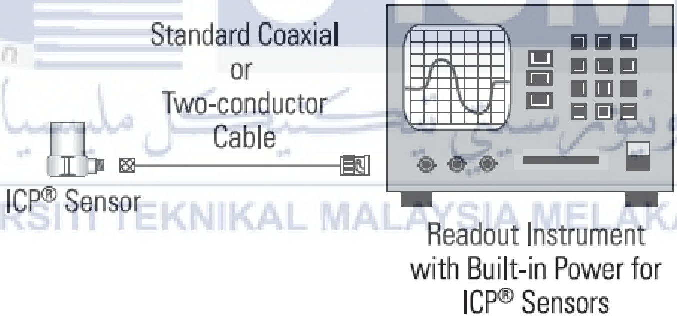

Figure 3.4: Typical ICP sensor system. from the source (http://www.pcb.com/Resources/Technical-Information/tech_signal)

The functions of ICP sensors to provides charge output from the system and comes with many advantages:

1. Fixed voltage sensitivity.
2. Low output impedance.
3. High quality of voltage output.
4. Intrinsic sensor.
5. Data acquisition instrument.

3.3.3 PC data acquisition (DAQ) system

Data acquisition system is the process of computing a real – world signal such as voltage pulse directly into the computer for analyzing, processing and manipulating. The real – world signal represents by a physical phenomenon will be optimize in term of performance and handling capacity. Analog data signal is required for the real – world signal to be transformed into the digital signal form for the processing transmission and display purposed. Personal Computer (PC) hardware and software are easy and efficient adoption in various accuracy and precision of the measurement and complex control application. The conversion of a real world analog signal to the digital data needed control application and PC based measurement to analyses the input signal (S. Kuamr & S. Mohammad., 2010).

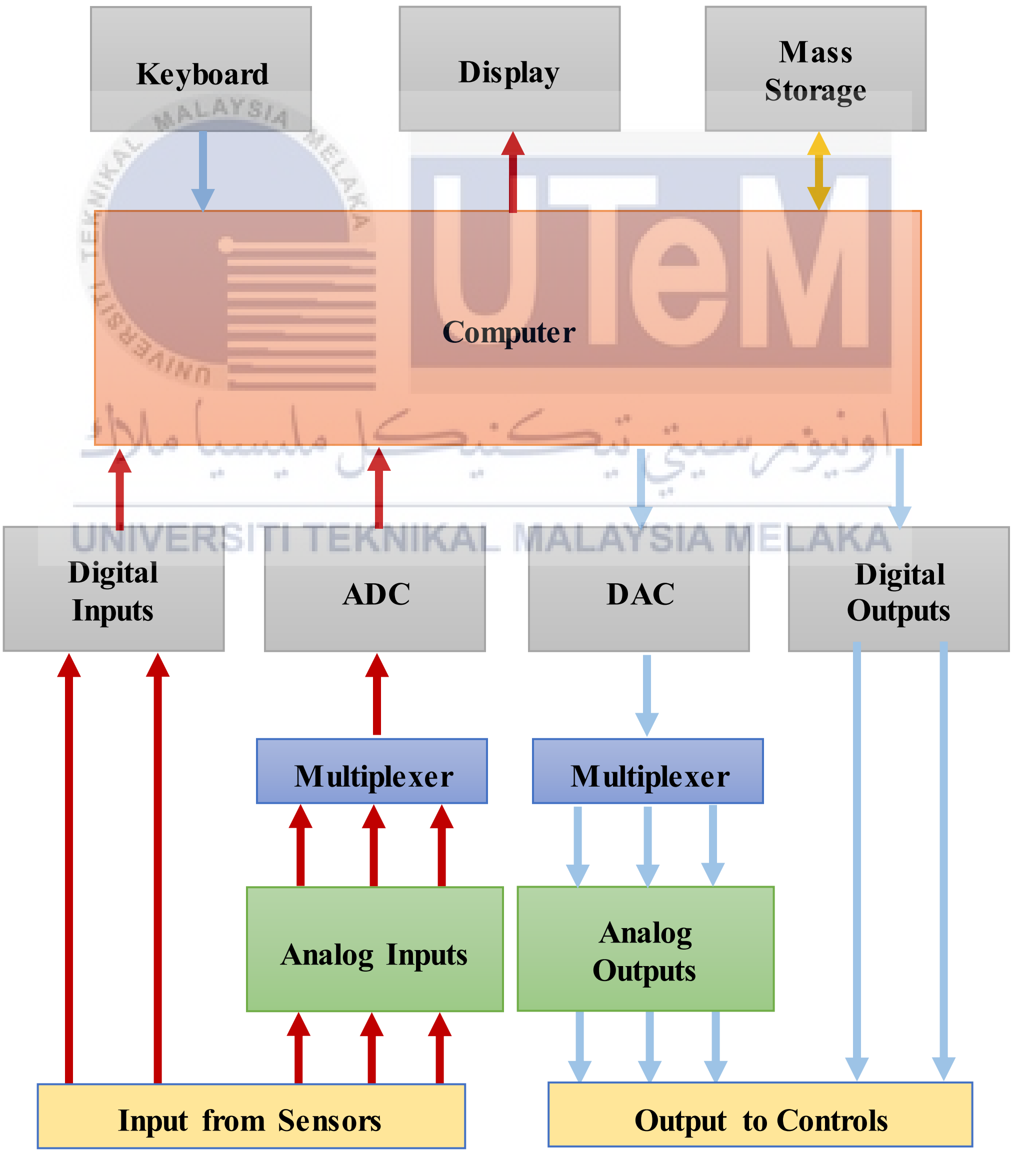

Figure 3.5: Simplified Block Diagram of a Data Acquisition system.

3.3.4 Clamping device

The clamping used in the experiment are rigid and solid in density to hold the metal plate in place during the experiment. The clamping should not move at all when the metal plate vibrated. The clamping is divided by two regions are base and head.

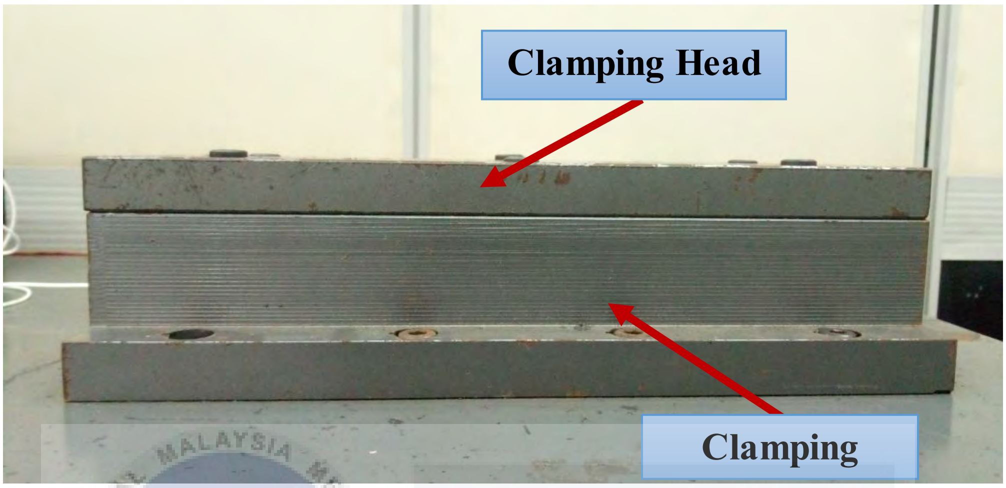

Figure 3.6: Clamping device.

3.4 Experiment and simulation

The actual experiment will be take place by using the stainless steel circular plate as the testing materials for dynamic properties experiment. The simulation software will be used is DEWETRANS program to enable the transient measurement of the DAQ system.

3.4.1 Experiment preparation

The experiment takes placed at the Instrumentation and Measurement laboratory. A experiment was conducted on stainless steel circular plate to analyses the dynamic properties of the materials and occupants the data and result of the testing, to get an accurate and precision result the experiment will be repeated to archiving a good result.

The experiment will covered the data value in term of period (T), Amplitude (A), Frequency (f), Logarithmic decrement (δ) and damping ratio (ζ). All the data recorded from the experiment and simulation will be using in analyzing and calculating the dynamic properties analysis. Therefore, the procedure of experiment shown as below:

1. The tested circular plate was clamped to the table by using clamps. The plate was tightly fixed at the center.

2. The accelerometer was connected to the input jack of a second power unit using microdot – BNC cable. The output jack of the power unit was connected to Channel 4 of the DAQ system using a BNC cable.
3. The accelerometer was placed to the side of the circular plate. An adhesive wax was supplied in between of accelerometer and circular plate to stick the accelerometer in placed to the structure.
4. Both of the power unit and DAQ system was turned on and prepared for experiment process.

3.4.2 Measurement of damping ratio (DEWETRANS)

By using the already installed DEWETRANS software on the computer laboratory. The software was directly opened and make sure all the devices connection was in good condition and ready for experiment. For measuring the damping ratio:

1. The DEWETRANS program was run to enable the measurement of DAQ system.

Figure 3.7: Running the program.

2. The Channel 3 and 4 were set to "Used" mode by clicking the channel.

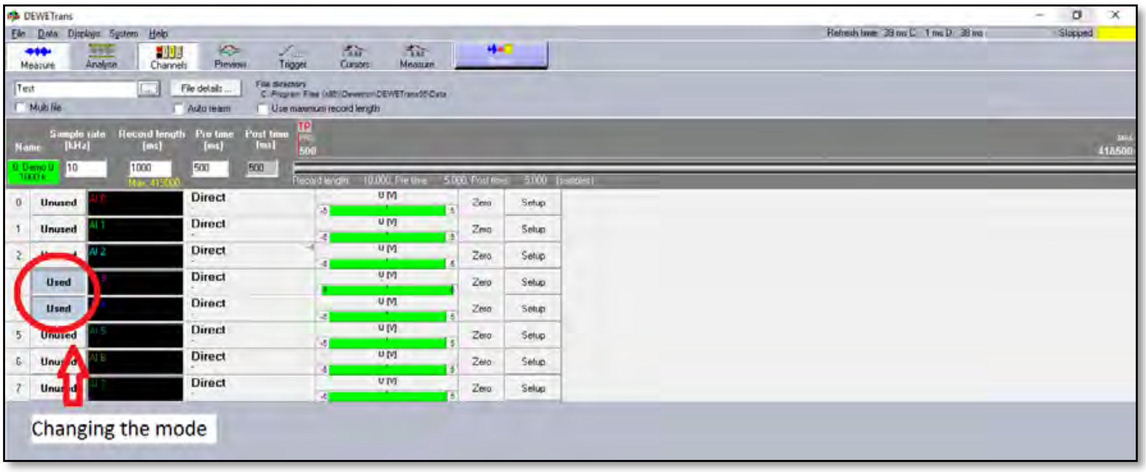

Figure 3.8: Changing channel mode.

3. The sensitivity for the channels also was set according to the sensitivity of the transducers.

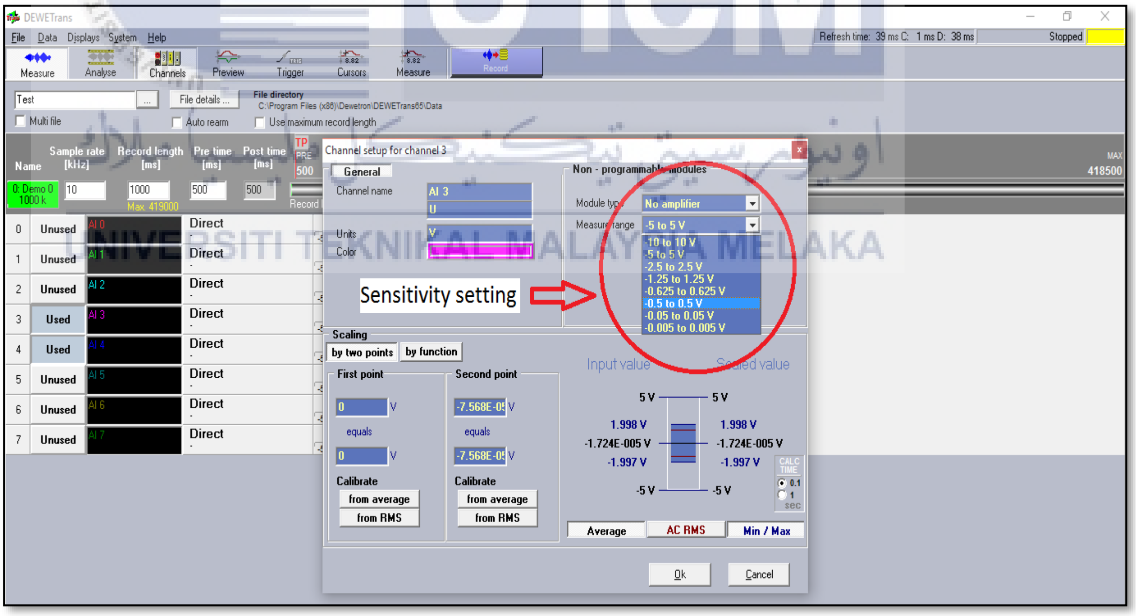

Figure 3.9: Channel sensitivity.

4. Channel 3 on the upper half and Channel 4 on the lower half was displayed on the “scope” screen.

Figure 3.10: Scope screen.

5. Trigger Source was set to Channel 3 and the trigger level must be around 10g.

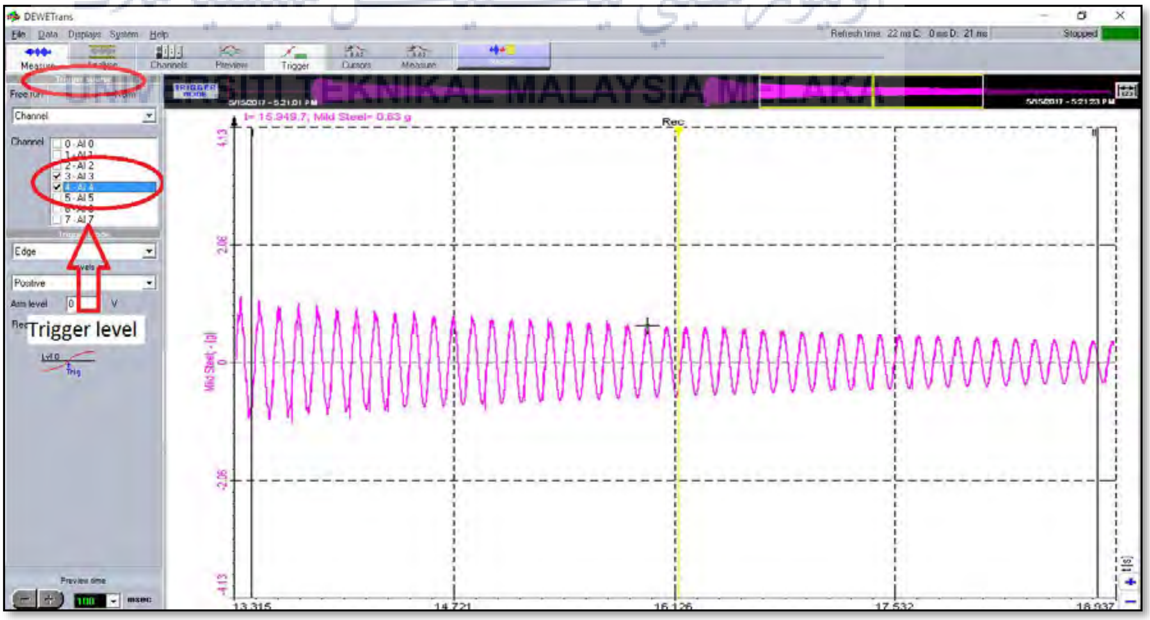

Figure 3.11: Trigger source.

6. The Record button on the scope was pressed and the circular plate was pushed down, then immediately released the beam to vibrate.

Figure 3.12: Position of record button.

7. A free response time history of acceleration was resulted an exponentially decaying sine wave. The cursor was used to measure and record the amplitude (A) between two consecutive maximum and minimum. The step was repeated for other consecutive peaks to confirm the values.

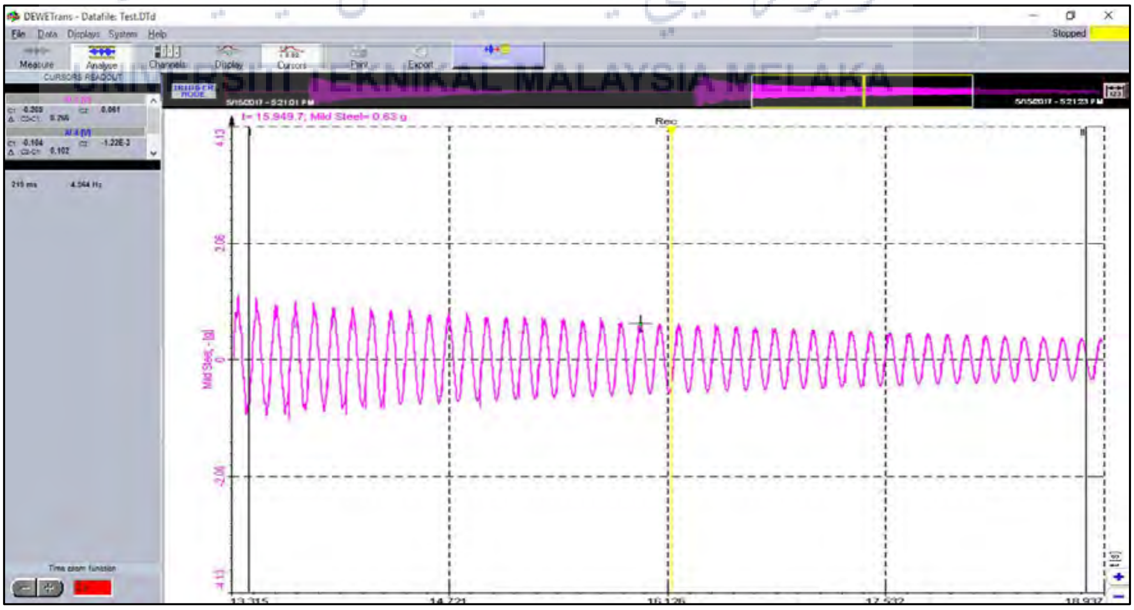

Figure 3.13: Record maximum and minimum peak.

8. By using the scope cursor, the voltage values of several maxima and minima was measured to estimate the damping ratio with the number of cycles between point.

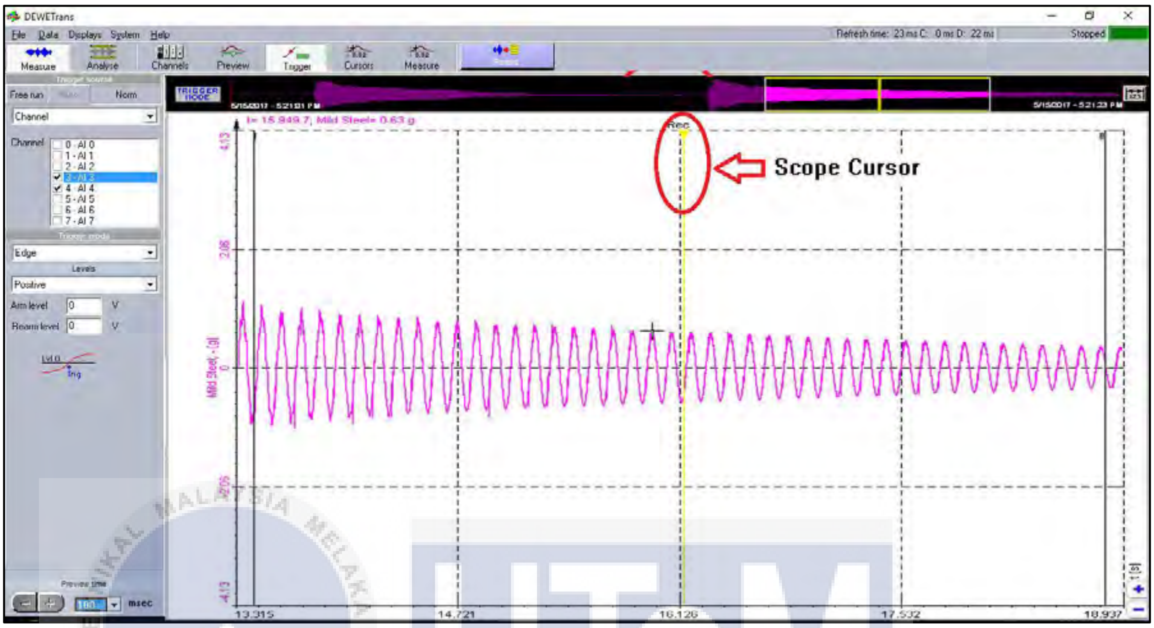

Figure 3.14: Scope cursor.

9. The screen was printed to include the report writing.

3.5 Experiment Analysis Derivation on cantilever beam

Analysis will be presented on how the propagation of vibration on the circular plate and also the mechanical energy conversion of the vibrating structure problem. Solutions will be proposed based on the analysis. There are two method calculation of determining the damping ratio need to be highlighted in the study:

The method used are:

- Logarithmic Decrement Method
- Half – Power Bandwidth Method

3.5.1 Experiment for cantilever beam

Apparatus setup:

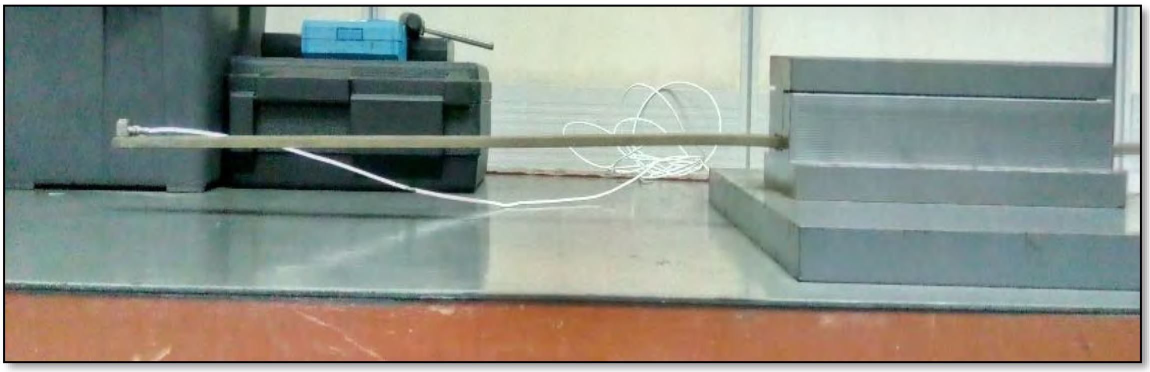

Figure 3.15:Apparatus setup.

Figure 3.16:Schematic diagram for cantilever beam.

In collecting and organizing raw data during an experiment and also for representing final data to be included in a report, tables and figures are used to reorganized and represented the data in arranged situation.

Table 3.1: Maximum or minimum peaks of the oscillation.

Number of cycle (N)	Amplitude point (A)
1	0.64
2	0.61
3	0.60
4	0.59
5	0.57
6	0.56
7	0.54
8	0.53
9	0.51
10	0.50
11	0.48

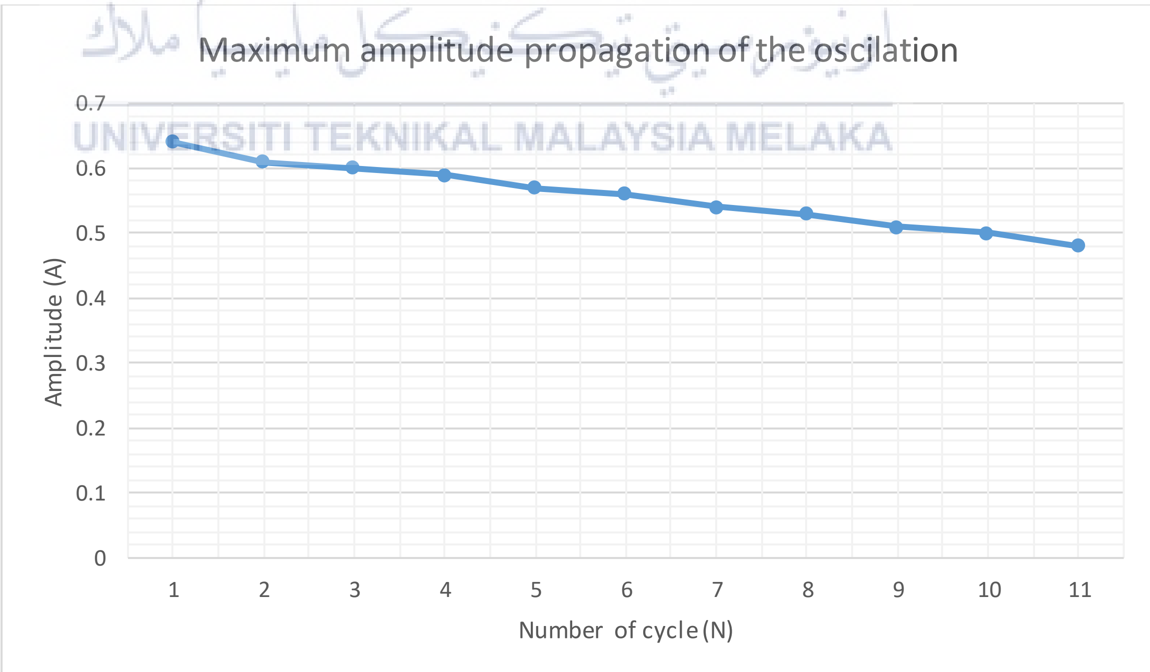

Figure 3.17: Graph of maximum amplitude of each cycle.

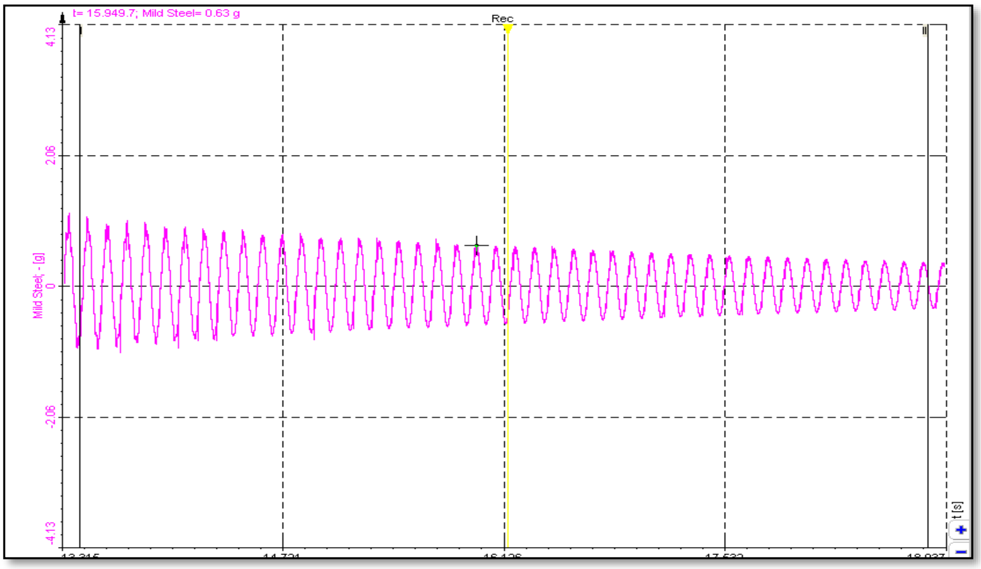

Figure 3.18: Sinusoidal graph propagation for cantilever beam.

Table 3.2: Logarithmic decrement and damping ratio of the system.

Logarithmic decrement, (δ)	Damping ratio, (ξ)
0.0480	0.0764
0.0166	0.0264
0.0168	0.0267
0.0690	0.1100
0.0176	0.0280
0.0362	0.0576
0.0186	0.0296
0.0384	0.0611
0.0198	0.0315
0.0408	0.0650

Therefore, the average damping ration, ξ of the system is **0.05123**

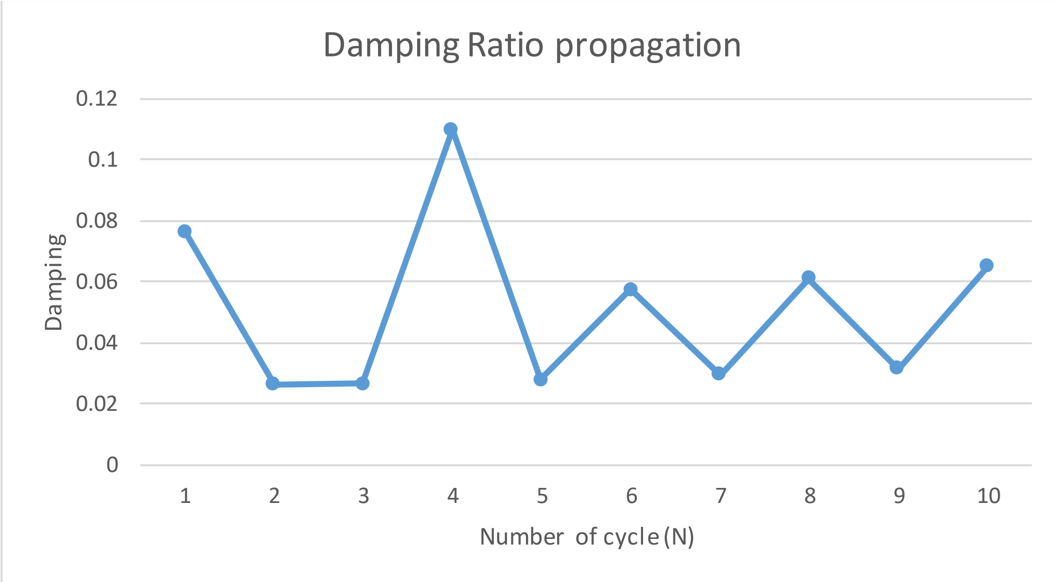

Figure 3.19: Graph of damping propagation of each cycle.

3.5.2 Sample calculation

Logarithmic Decrement Method,

$$\delta = \frac{1}{N} \ln \frac{x(t_n)}{x(t_{n+1})}$$

$$\delta = \frac{1}{1} \ln \frac{0.64}{0.61}$$

$$\delta = 0.0240$$

Damping ratio calculation,

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}}$$

$$\xi = \frac{0.0480}{\sqrt{(2\pi)^2 + 0.0480^2}}$$

$$\xi = 0.0764$$

Table 3.3:Measured frequencies of Half – Power Bandwidth method.

f_1(Hz)	f_0(Hz)	f_2(Hz)
7.324	7.93	8.354

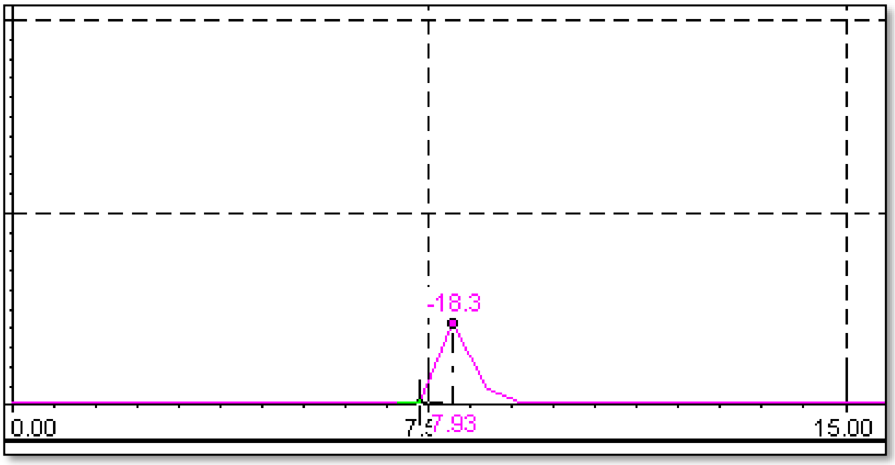

Figure 3.20: (FFT) graph signal, shows that most of the power is at one frequency after (- 3dB) for Q factor calculation.

Q factor calculation,

$$Q = \frac{f_0}{f_2 - f_1}$$

$$Q = \frac{7.93}{8.354 - 7.324}$$

$$Q = 7.699$$

Damping ratio from Q factor value,

$$\xi = \frac{1}{2Q}$$

$$\xi = \frac{1}{2(7.699)}$$

$$\xi = 0.0649$$

3.5.3 Percentage of error

Therefore, the percentage of error between two method, Logarithmic decrement and Half – power bandwidth derived by,

Percentage of error,

$$\% = \left| \frac{Experiment - Theoritical}{Theoritical} \right| \times 100\%$$

Percentage of error,

$$\% = \left| \frac{0.05123 - 0.0649}{0.0649} \right| \times 100\%$$

Percentage of error,

$$\% = 21.13\%$$

3.6 Summary

The result of damping ratio of the experiment on the cantilever beam shows the difference on both theoretical value and experimental value with the 21.13% percent of percentage of error. The experiment consist error during the experiment work was carried out, the error in this experiment are random error, and systematic error that cause the data taken was inaccurate and the experiment categories as unsuccessful test.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The experiment was done repeatedly by using the stainless steel circular plate as the specimen materials. The experiment was conducted at UTeM industrial campus, Fasa B, Melaka. The setup and apparatus are already prepared in the Measurement and Instrumentation Laboratory.

The experiment trial was conducted first to calibrate the accuracy of the equipment and device also the systematic error on the apparatus. After all the apparatus been prepared and functionally, the experiment is ready to be conducted.

Firstly, the circular plate are clamped rigidly on the clamping rig and the experiment was started with the gently push on end of the circular plate tips. The data variation of vibration propagation will be display on the monitor and recorded to further analysis.

In this chapter, the result of the analysis of the experiment with the theoretical analysis are compared and defined.

4.2 Device

The device use to trace the propagation of the vibration on the plate is accelerometer. This device is capable to track the propagation sensitivity up to 121.6 mV/g. The vibration recorded will be displays in various value such as amplitude, frequency, time, period, etc.

The clamping device used in this experiment was the same clamp for the cantilever beam experiment. The only different is the method of clamping the circular plate, previously the beam were clamped by hanging the other tip. For the circular plate, the head of the clamp was rotate upward to getting the flat surface, the base of the clamp is fixed in position and after setup for the clamping is done, the circular plate is position fitly to its position.

4.3 Apparatus Setup

Figure below show the apparatus setup for clamping the circular plate in place before run the experiment.

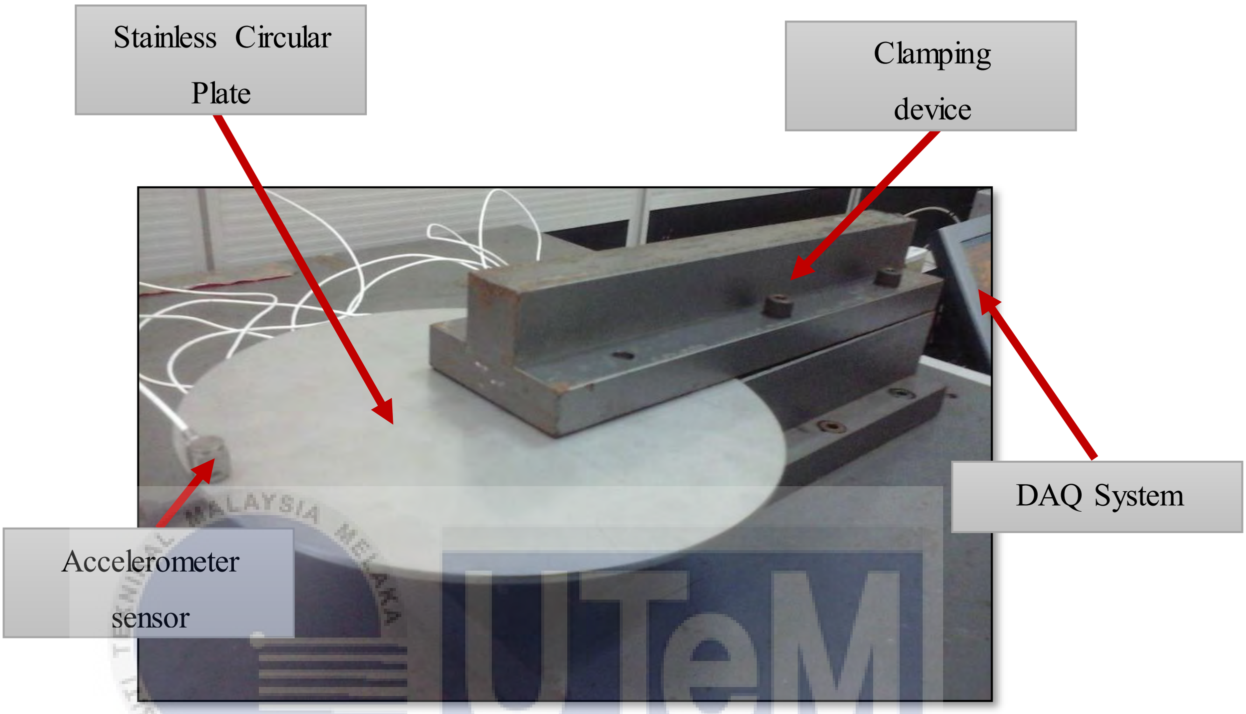

Figure 4.1: Apparatus of the experiment.

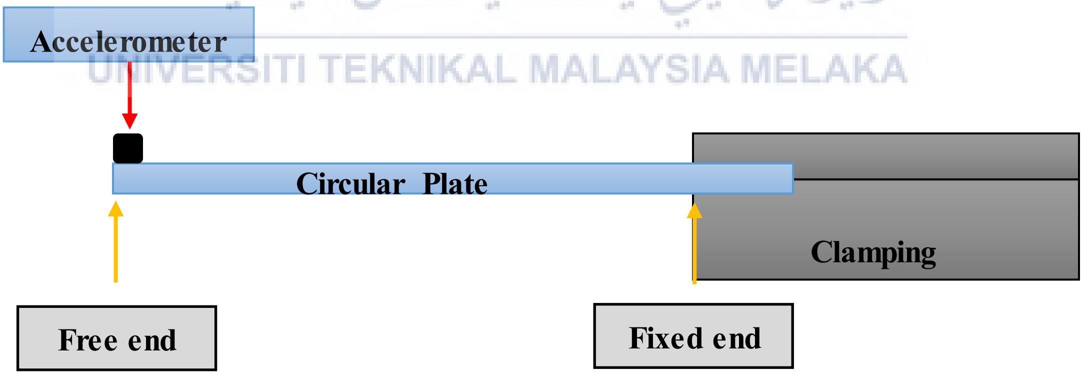

Figure 4.1:Schematic diagram for Circular plate.

4.4 Experiment Analysis (without isolator)

In collecting and organizing raw data during an experiment and for representing final data to be included in a report, tables and figures are used to reorganized and represented in this report. For the first phase of the actual experiment conducted, the force applied at the end tip of the plate are randomly. The circular plate was clamped between head and base clamping without isolator.

4.4.1 Result Tabulation.

Table 4.1:Maximum or minimum peaks of the oscillation

Number of cycle (N)	Amplitude point (A)		
	Experiment 1	Experiment 2	Experiment 3
1	0.85	0.97	1.29
2	0.78	0.86	1.11
3	0.75	0.75	0.81
4	0.70	0.60	0.69
5	0.60	0.58	0.51
6	0.50	0.55	0.39
7	0.44	0.46	0.37
8	0.40	0.41	0.32
9	0.40	0.37	0.27
10	0.35	0.34	0.24
11	0.32	0.34	0.24

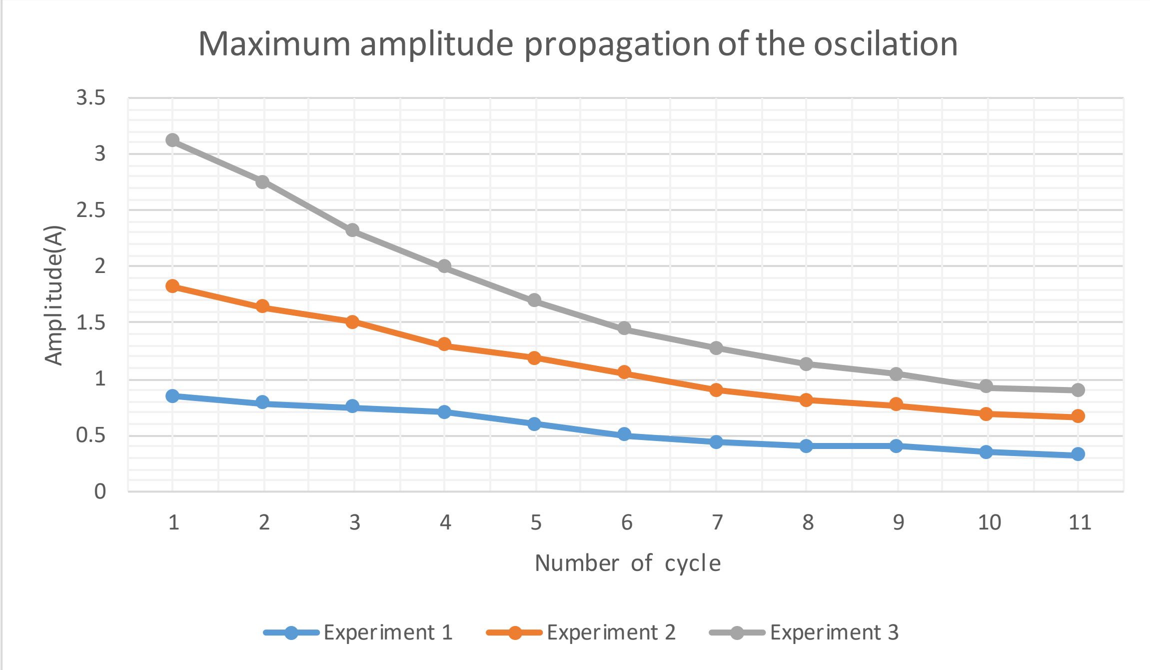

Figure 4.2: Graph of maximum amplitude of three experiment.

The graph shows the amplitude value of each experiment conducted. The propagation of three experiment decrease over time because of the free damped vibration occur, amplitude value drops constantly every cycle.

Table 4.2:Time for one cycle

	$t_1(s)$	$t_2(s)$
Experiment 1	2.793	2.806
Experiment 2	2.751	2.764
Experiment 3	2.751	2.764

Table 4.3:Period, T(s)

	T (s)
Experiment 1	0.013
Experiment 2	0.013
Experiment 3	0.013

The period shows in Table 4.3, contains a constant time interval every maximum amplitude peak in sequence. Therefore, the frequency of the circular plate also the same.

4.4.2 Data analysis

Table 4.4:Logarithmic decrement and damping ratio of the system.

	Logarithmic Decrement, (δ) and Damping Ratio, (ζ)					
	Experiment 1		Experiment 2		Experiment 3	
	(δ)	(ζ)	(δ)	(ζ)	(δ)	(ζ)
1	0.0859	0.0861	0.120	0.0191	0.1503	0.0239
2	0.0392	0.00239	0.137	0.0218	0.3151	0.0501
3	0.0690	0.0110	0.223	0.0355	0.1603	0.0255
4	0.1540	0.0245	0.034	0.00541	0.3022	0.0480
5	0.182	0.0290	0.0531	0.00845	0.268	0.0426
6	0.128	0.0204	0.179	0.0285	0.0526	0.00837
7	0.0953	0.0152	0.115	0.0183	0.145	0.0231
8	0	0	0.103	0.0164	0.170	0.0270
9	0.134	0.0213	0.0846	0.0135	0.118	0.0188
10	0.090	0.0143	0	0	0	0

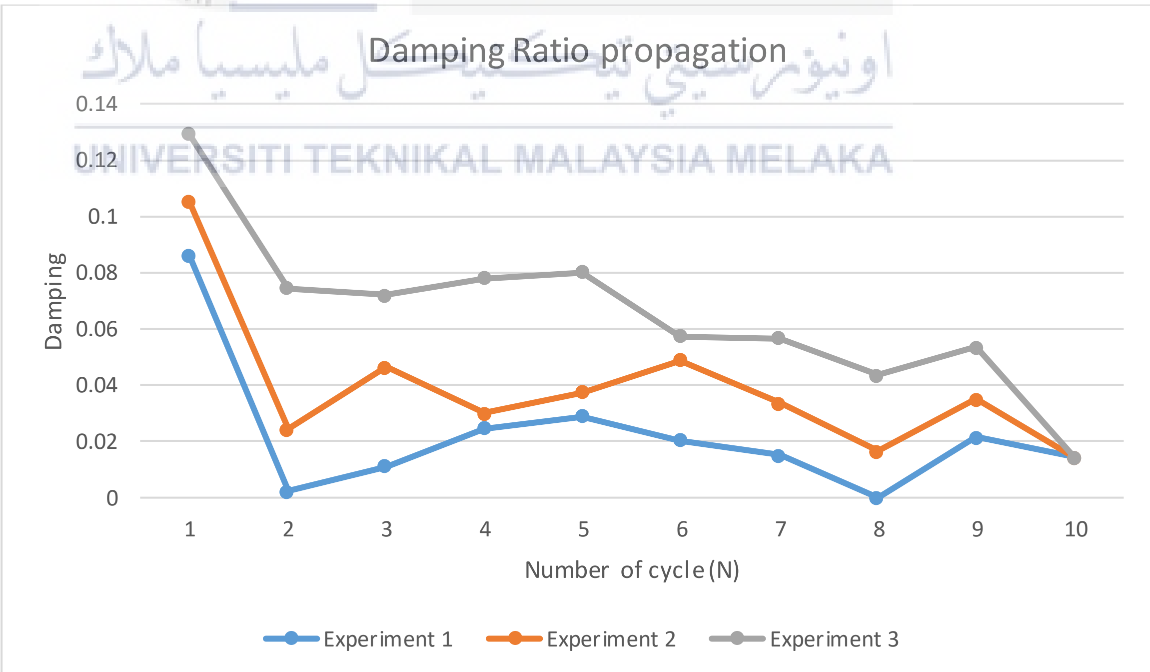

Figure 4.3: Damping propagation of three experiment.

The graph above (Figure 4.3) shows that the value of damping ratio of each cycle, the calculation from logarithmic decrement method were used to determine the damping for 10 cycle of the three repeatable experiment data.

Table 4.5:Average value of damping ratio

ζ avg (Experiment 1)	ζ avg (Experiment 2)	ζ avg (Experiment 3)
0.022419	0.016696	0.026737

Therefore, the average for each experiment of the 10 cycle were calculated and this damping ratio value are the value from the experimental by using the logarithmic decrement method.

Logarithmic decrement calculation,

$$\delta = \frac{1}{N} \ln \frac{x(t_n)}{x(t_{n+1})}$$

$$\delta = \frac{1}{1} \ln \frac{0.85}{0.78}$$

$$\delta = 0.0859$$

Damping ratio calculation,

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}}$$

$$\xi = \frac{0.0859}{\sqrt{(2\pi)^2 + 0.0859^2}}$$

$$\xi = 0.0861$$

The damped natural frequency to the natural frequency calculation,

$$\frac{\omega_d}{\omega_n} = \sqrt{1-\xi^2}$$

$$\frac{\omega_d}{\omega_n} = \sqrt{1-0.0861^2}$$

$$\frac{\omega_d}{\omega_n} = 0.9996$$

Table 4.6:Measured frequencies of Half – Power Bandwidth method.

Experiment 1:

f_1(Hz)	f_0(Hz)	f_2(Hz)
76.904	78.735	79.956

Experiment 2:

f_1(Hz)	f_0(Hz)	f_2(Hz)
75.684	77.515	79.346

Experiment 3:

f_1(Hz)	f_0(Hz)	f_2(Hz)
75.684	77.515	79.346

From the data tabulation Table 4.6, the frequency result shows there are slightly different between each of the experiment except experiment 2 and experiment 3. The frequency pointed the resonance frequency, upper 3dB frequency and lower 3dB frequency with a constant value.

Q factor calculation,

$$Q = \frac{f_0}{f_2 - f_1}$$

$$Q = \frac{78.735}{79.956 - 76.904}$$

$$Q = 25.798$$

Damping ratio calculation based on the value of Q factor,

$$\xi = \frac{1}{2Q}$$

$$\xi = \frac{1}{2(25.798)}$$

$$\xi = 0.01938$$

Table 4.7:Half – Power Bandwidth

ζ (Theoretical 1)	ζ (Theoretical 2)	ζ (Theoretical 3)
0.01938	0.02362	0.02362

By using half – power bandwidth method, the value of theoretical value are archive for the calculation of Q factor. The quantitative measure of the damping ratio of three theoretical value were recorded in Table 4.7.

4.4.3 Percentage of error of the experiment

Therefore, the percentage of error between two method, Logarithmic decrement and Half– power bandwidth derived by,

Percentage of error,

$$\% = \left| \frac{Experiment - Theoritical}{Theoritical} \right| \times 100\%$$

Percentage of error,

$$\% = \left| \frac{0.022419 - 0.019380}{0.019380} \right| \times 100\%$$

Percentage of error,

$$\% = 15.68\%$$

Table 4.8:Percentage of error each experiment

Experiment 1 (%)	Experiment 2 (%)	Experiment 3 (%)
15.68	29.31	13.20

In Table 4.8, the percentage of error calculate from the comparison between experiment 1, experiment 2, and experiment 3 value with the theoretical value were calculated. From the table above shows that there are a lot of differences value compared with experiment and theoretical as shows in Table 4.8 percentage of error each experiment.

4.5 Experiment Analysis (With Isolator)

For the second attempt of the experiment the thin rubber line was placed between upper plate and lower plate of circular plate act as the isolator. The force applied randomly during this experiment, and also same position of clamping.

4.5.1 Result tabulation.

Table 4.9:Maximum or minimum peaks of the oscillation

Number of cycle (N)	Amplitude point (A)		
	Experiment 1	Experiment 2	Experiment 3
1	2.42	1.26	1.28
2	2.04	1.11	1.12
3	1.84	0.93	0.93
4	1.75	0.84	0.82
5	1.40	0.70	0.76
6	1.21	0.69	0.75
7	1.19	0.58	0.64
8	1.03	0.56	0.63
9	0.90	0.54	0.54
10	0.83	0.48	0.46
11	0.75	0.40	0.42

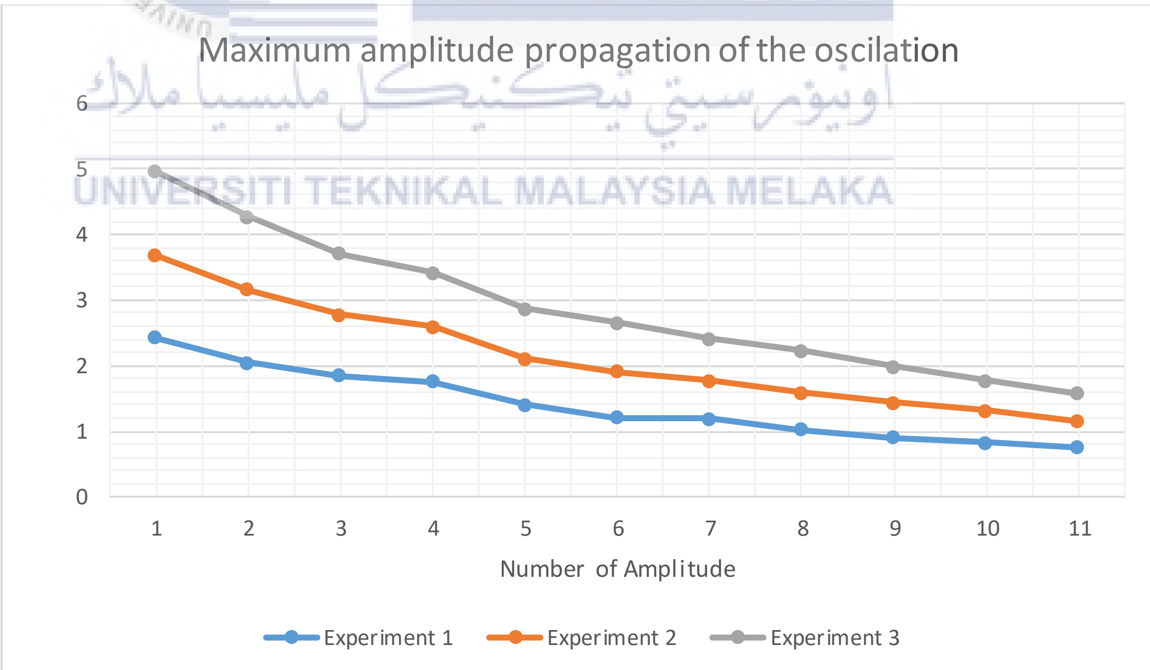

Figure 4.4: Graph of maximum amplitude of each experiment.

In comparison between the experiment without the isolator, the data also recorded there are decreasing value of amplitude over time, this is because the experiment conducted and the propagation of the circular plate is a damped natural vibration.

Table 4.10:Time for one cycle

	t1 (s)	t2 (s)
Experiment 1	2.279	2.297
Experiment 2	3.152	3.171
Experiment 3	5.153	5.171

Table 4.11:Period, T

	T (s)
Experiment 1	0.018
Experiment 2	0.019
Experiment 3	0.018

Table 4.11 shows the period of each consecutive maximum amplitude, all of the experiment recorded constant period value with ± 0.001. Therefore, each of the experiment have a same time of propagation time in every cycle.

4.5.2 Data analysis

The figures below show the propagation graph of circular plate after applied force on each repeat experiment and the Fast Fourier transform (FFT) graph of that signal, shows that most of the power is at one frequency, approximating a sine wave to determining the half – power bandwidth.

First experiment:

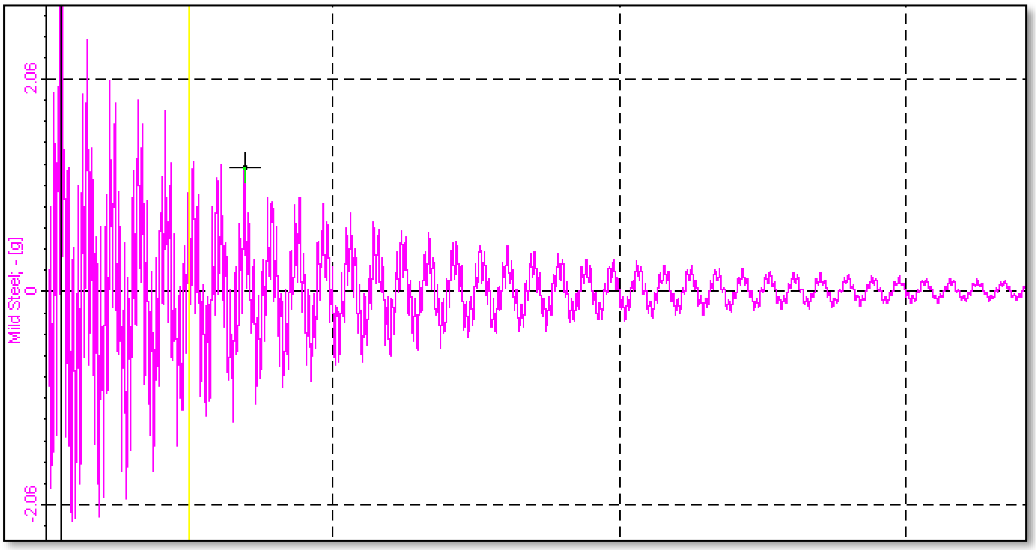

Figure 4.3 : Sinusoidal graph propagation for experiment 1.

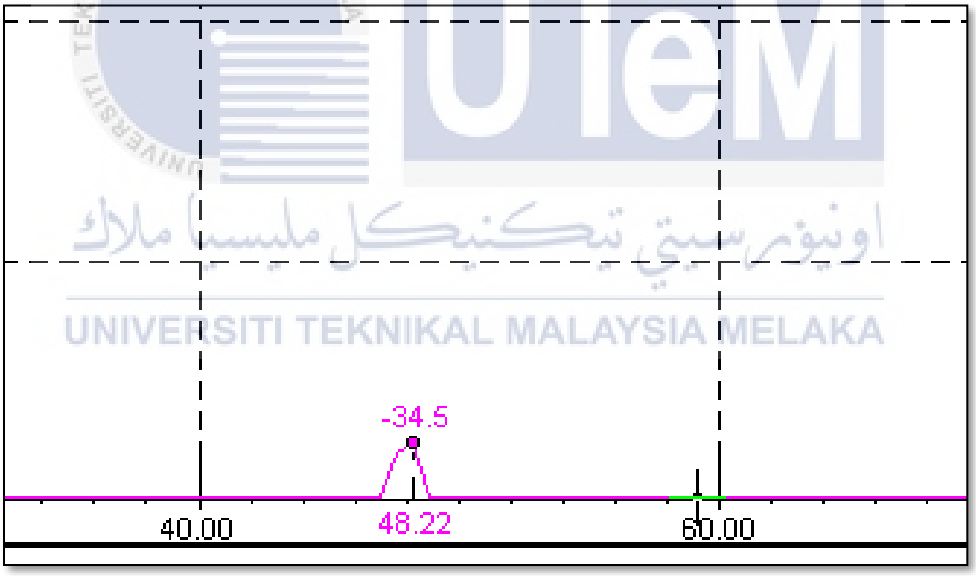

Figure 4.4: (FFT) graph signal, shows that most of the power is at one frequency after (- 3dB) for experiment 1.

Second experiment:

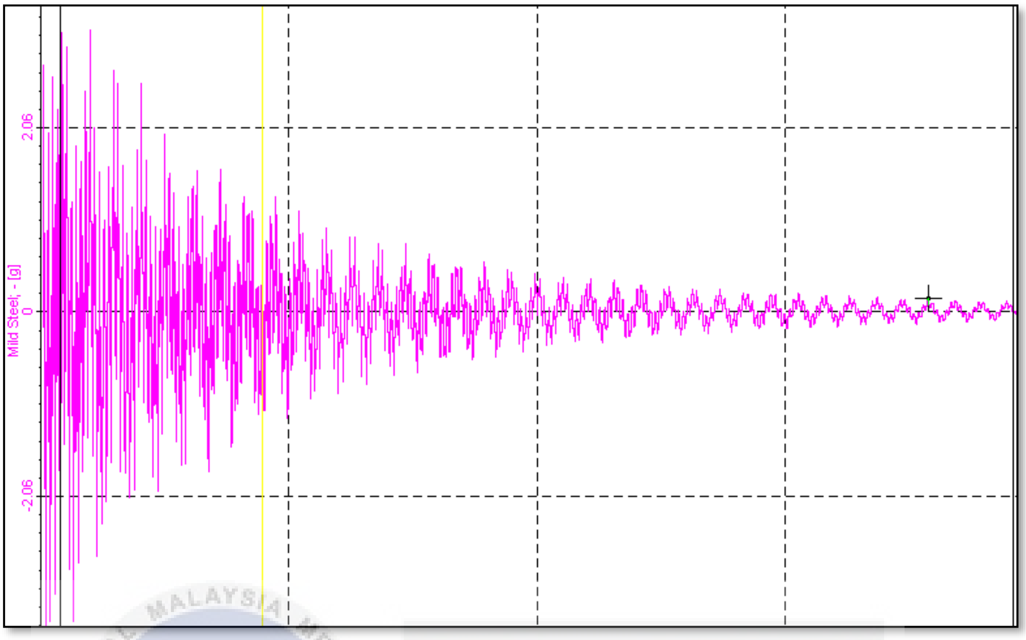

Figure 4.5 : Sinusoidal graph propagation for experiment 2.

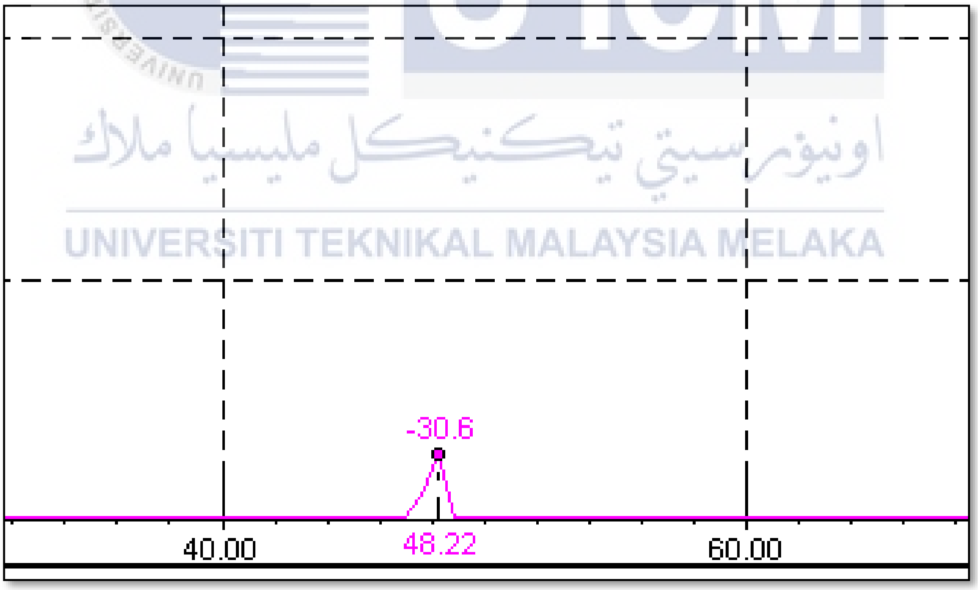

Figure 4.6: (FFT) graph signal, shows that most of the power is at one frequency after (- 3dB) for experiment 2.

Third experiment:

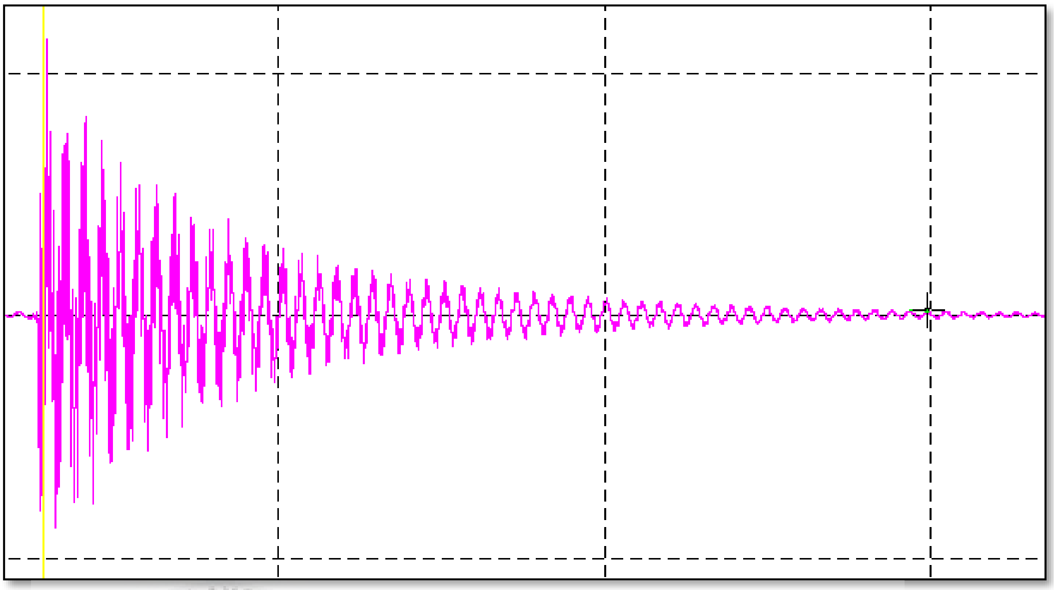

Figure 4.7 : Sinusoidal graph propagation for experiment 3.

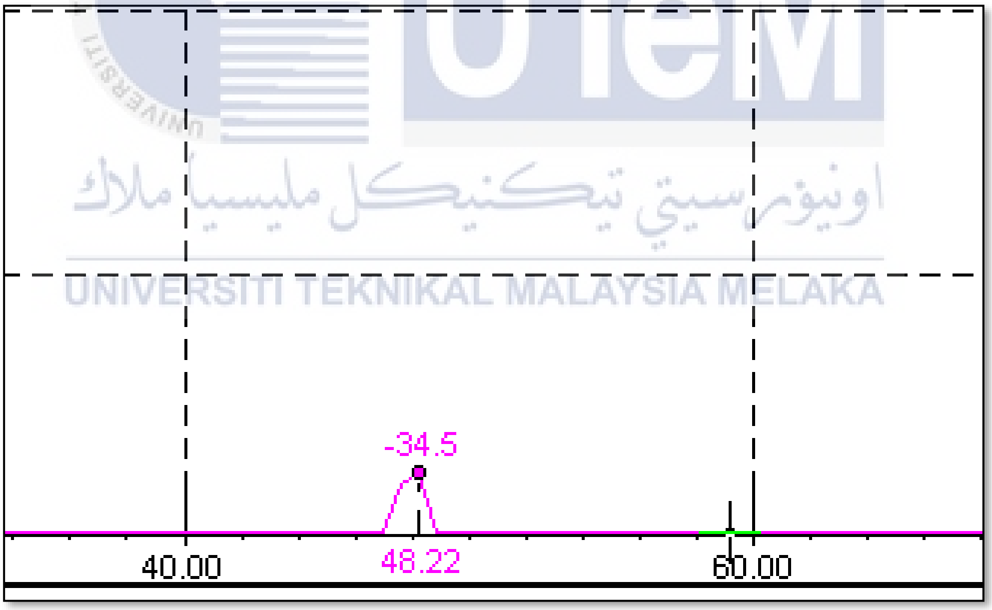

Figure 4.8: (FFT) graph signal, shows that most of the power is at one frequency after (- 3dB) for experiment 3.

Table 4.12:Logarithmic decrement and damping ratio of the system.

	Logarithmic Decrement, (δ) and Damping Ratio, (ζ)					
	Experiment 1		Experiment 2		Experiment 3	
	(δ)	(ζ)	(δ)	(ζ)	(δ)	(ζ)
1	0.1708	0.0271	0.1268	0.0202	0.1335	0.0212
2	0.1032	0.01642	0.1770	0.0282	0.1859	0.0296
3	0.0501	0.0080	0.1018	0.0162	0.1259	0.0200
4	0.2231	0.0355	0.1823	0.0290	0.0760	0.0121
5	0.1459	0.0027	0.0144	0.0023	0.0132	0.0021
6	0.0167	0.0232	0.1737	0.0276	0.1586	0.0252
7	0.2793	0.0444	0.0351	0.0056	0.0157	0.0025
8	0	0	0.0364	0.0058	0.1542	0.0254
9	0.0810	0.0129	0.1178	0.0187	0.1603	0.0255
10	0.1014	0.01613	0.1823	0.0290	0.0910	0.0145

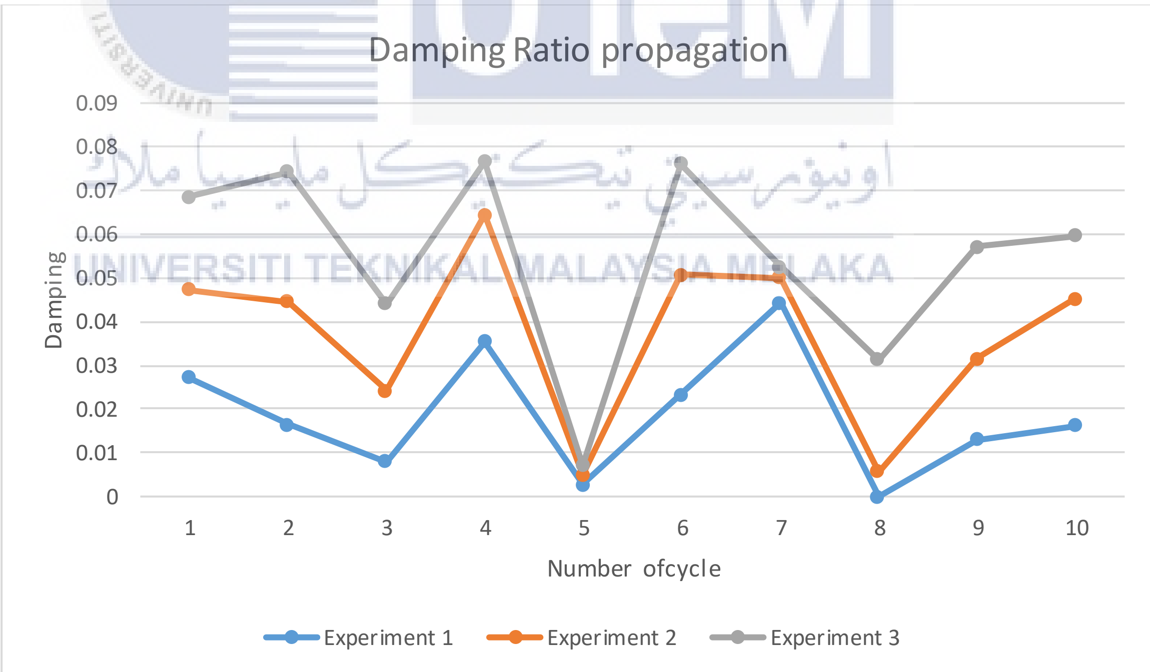

Figure 4.5: Graph of damping ratio propagation.

The graph above (Figure 4.5) shows that the value of damping ratio of each cycle, the calculation from logarithmic decrement method were used to determine the damping for 10 cycle of the three repeatable experiment data.

Table 4.13:Average value of damping ratio

ζ avg (Experiment 1)	ζ avg (Experiment 2)	ζ avg (Experiment 3)
0.018635	0.018260	0.017810

Therefore, the average for each experiment of the 10 cycle were calculated and this damping ratio value are the value from the experimental by using the logarithmic decrement method.

Logarithmic decrement calculation,

$$\delta = \frac{1}{N} \ln \frac{x(t_n)}{x(t_{n+1})}$$

$$\delta = \frac{1}{1} \ln \frac{1.26}{1.11}$$

$$\delta = 0.1268$$

Damping ratio calculation,

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}}$$

$$\xi = \frac{0.1268}{\sqrt{(2\pi)^2 + 0.1268^2}}$$

$$\xi = 0.0202$$

The damped natural frequency to the natural frequency calculation,

$$\frac{\omega_d}{\omega_n} = \sqrt{1-\xi^2}$$

$$\frac{\omega_d}{\omega_n} = \sqrt{1-0.0202^2}$$

$$\frac{\omega_d}{\omega_n} = 0.9998$$

Table 4.14:Measured frequencies of Half – Power Bandwidth method.

Experiment 1:

f_1(Hz)	f_0(Hz)	f_2(Hz)
47.064	48.220	48.935

Experiment 2:

f_1(Hz)	f_0(Hz)	f_2(Hz)
47.498	48.220	49.296

Experiment 3:

f_1(Hz)	f_0(Hz)	f_2(Hz)
47.572	48.220	49.357

From the data tabulation Table 4.14, the resonance frequency in each experiment 1, experiment 2 and experiment 3 recorded the same result with 48.220 Hertz. The frequency pointed the resonance frequency is constant, except the upper 3dB frequency and lower 3dB frequency have a slightly different data value.

Q factor calculation,

$$Q = \frac{f_0}{f_2 - f_1}$$

$$Q = \frac{48.220}{48.935 - 47.064}$$

$$Q = 25.772$$

Damping ratio calculation based on the value of Q factor,

$$\xi = \frac{1}{2Q}$$

$$\xi = \frac{1}{2(25.772)}$$

$$\xi = 0.019400$$

Table 4.15:Half – Power Bandwidth

ζ (Theoritical 1)	ζ (Theoritical 2)	ζ (Theoritical 3)
0.019400	0.018644	0.018509

4.5.3 Percentage of error of the experiment

Therefore, the percentage of error between two method, Logarithmic decrement and Half– power bandwidth derived by,

Percentage of error,

$$\% = \left| \frac{Experiment - Theoritical}{Theoritical} \right| \times 100\%$$

Percentage of error,

$$\% = \left| \frac{0.019400 - 0.018635}{0.018635} \right| \times 100\%$$

Percentage of error,

$$\% = 4.78\%$$

Table 4.16:Percentage of error each experiment

Experiment 1 (%)	Experiment 2 (%)	Experiment 3 (%)
4.78	2.06	3.78

The percentage of error between each experiment consist of three different percentage that conclude the successor of this experiment. From three of this percentage value of the experiment pass the qualifier to same or close enough to theoretical value.

4.6 Summary

From the experiment result above in, the damping ratio of the stainless steel, circular plate can be determined by using the Logarithmic decrement and Half- Power Bandwidth. The data resulted on the logarithmic decrement method contains an error that recorded inconsistent amplitude that cause the data is slightly inaccurate. The Half – Power bandwidth method on each experiment recorded a precision and accurate data for the Q factor, in process determining the damping ratio.

Preliminary experiment also been conducted to obtaining the result archived for damping ratio of the material by using the DEWETRANS program and compare the experiment result with the theoretical value. This experiment result consists an error during the experiment work was carried out, the error in this experiment are random error, and systematic error. The preliminary experiment value will be used as guideline for the next experiment will be conducted soon.

The future experiment work will be including the actual tested materials and a new measurement for the apparatus in the Instrumentation and Measurement laboratory.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Throughout this research experiment (Determination of Dynamics Properties of Laminated Rubber Spring Metal on circular plate), the frequency value of $f_0, f_1,$ and f_2 in Q factor of the stainless steel circular plate above the -3db of each experiment recorded with different apparatus which are with isolator and without isolator, without changing the location of fixed end clamping position to preventing the error occur. The adjustment from the apparatus by adding the isolator layer between the circular plate have decrease the frequency on the stainless-steel plate.

Therefore, the propagation of maximum amplitude in 10 cycles in each experiment done, all the peak amplitude is damped constantly varies with time. The damping ratio archive from the Q factor calculation contribute an accurate data and result for resonance frequency, f_0 for the experiment. For maintaining the precision of the result, the experiment has been repeated three times and the average result among the total experiment was taken and recorded in the table.

Furthermore, the dynamic properties of a stainless-steel circular plate in the laminated rubber-metal spring (LR-MS) was successfully determined by using two method which are Logarithmic Decrement Method and Half-Power Bandwidth Method. Both methods successfully proving the reliable data and result for determining the damping ratio for stainless-steel circular plate during this study.

5.2 Recommendation

From the study that have been done, for the better study understanding on this topic in future, the recommendation can be made to improving the analysis are do more research of the apparatus setup to run the experiment, especially in sensor devices such as accelerometer and BNC cable. This two devices have very high sensitivity to trace and transmit the data from the sensors through the DAQ system by the computer. Therefore, the functionality of this critical sensor must be in perfect condition when running the experiment. Beside that's, the data taken from the system must be carefully selected, because somehow there will be a systematic error by the computer operating system that give slightly different result for the experiment.

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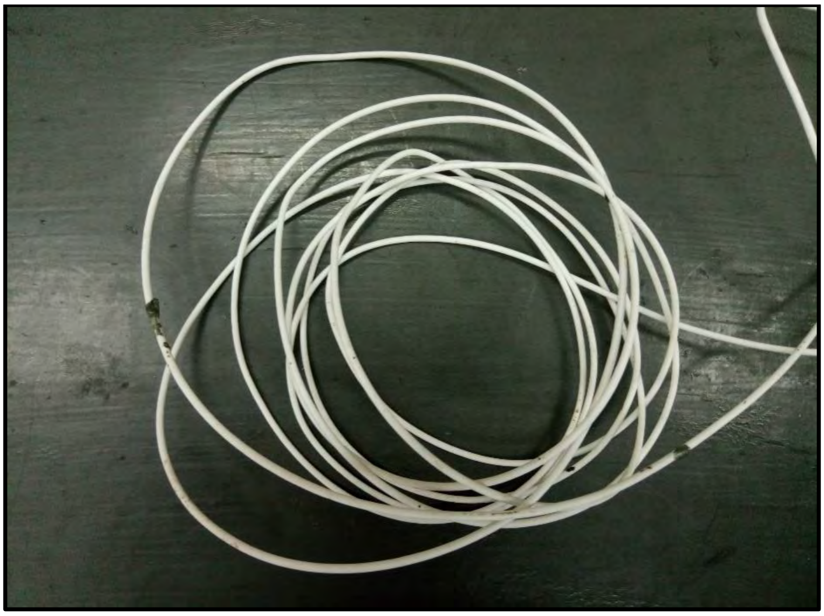
APPENDICES

Appendix A: Top view of the clamping.

Appendix B: Front view of the clamping.



Appendix C: BNC cable.

Appendix D: Accelerometer.